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Title: Development and Enhancement of a Model of Performance and Decision Making Under Stress in a Real Life Setting

Institution: University of Maryland at Baltimore and
Maryland Institute for Emergency Medical Systems

Current staff with percent effort of each on project:

Colin F. Mackenzie	15%
William Bernhard	5%
Kevin Gerold	5%
Brian McAlary	5%
Andy Trohanis	10%
Jim Brown	10%
Bob Moorman	10%
Peter Hu*	10%
James Black	50%

Sub-contract Man-Made Systems Corp.

Richard Horst	10%
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Daniel T. Smith	10%
Karen Webster	10%

* Mr. Hu replaces Xun Luo (see under Personnel and Administrative matters).

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Progress since 2nd Quarterly Report on the objectives of ONR Grant N00014-91-J1540 has been made as follows:

<u>Overview</u>

We have steadily made progress towards establishing a flexible and powerful capability for behavioral analysis of anesthesiologists performance in Shock Trauma. Our activities in the third quarter have continued to emphasize the development and refinement of the video data acquisition and data analysis systems. These activities have extended over more months than originally planned. Rather than procuring the video equipment for recording in all four locations in Shock Trauma at once, we choose~~, early on~~, to first develop and test one data acquisition system, to be sure that the components chosen would function together as intended. Furthermore, rather than delving into a large-scale task analysis and modeling effort prior to fully developing our video data analysis procedures, as had been originally planned, we decided to develop and evaluate our procedures throughout the envisioned data collection and analysis process with a focus on one decision tree, the Difficult Airway scenario. This strategy has proven to be very beneficial. ~~As detailed below~~, we have made some refinements in the data acquisition system that have resulted in a more useful system than could have been configured with the equipment originally envisioned, and we have gained some insights into how we should develop the initial MicroSAINT models of performance now that we have thought through a prototype empirical video analysis procedure. We expect that by the end of the upcoming fourth quarter we will have reached all of the milestones set forth for Year 1 of the contract.

Significant accomplishments in the just completed third quarter have included:

- Finalized both hardware and software configuration of the video data acquisition and data analysis systems (see Fig. 1 and Fig. 2); complete turn-key operation of the data acquisition systems has been achieved (the on-site anesthesiologist's only interaction with the system will be to change video tapes when the data acquisition computer sounds an alarm upon detecting an end-of-tape); we are also implementing the capability to off-load the physiological data stored on the data acquisition computer to our lab via an interface with the campus-wide data network.

- Installed two data acquisition systems in Shock Trauma and ordered the parts for the remaining two systems.

- Accomplished video taping of six trauma patient admissions for use in establishing our video analysis procedures.

- Prepared for routine video recording by briefing Shock Trauma staff, obtaining informed consent from the staff member participants who will be taped, and worked with LOTAS group in better defining experimental hypotheses of interest.

- Took delivery of the data analysis system hardware and software, and familiarized project staff with the OCS Tools software package.

- Developed a draft protocol for video analysis using OCS Tools.

- Prepared data-base management system (Paradox) file structures for physiological data (to be logged in real-time on the data acquisition systems), for the post-session questionnaires (to be completed by the anesthesiologist participants), and for the Neo-Personality Inventory data.

- Familiarized project staff and LOTAS group with a fatigue assessment test battery developed by the Naval Personnel R&D Center for the Office of Military Performance Assessment. We anticipate having at least a subset of the anesthesiologists complete approximately a 10-minute session on this test after cases that have been video taped.

- Completed a detailed task analysis of the Difficult Airway scenario. LOTAS group members will now review and comment on this effort prior to our translating this information into a MicroSAINT model.

<u>Refinement of Existing Task Analyses and Decision Trees</u>

Dr. Horst and Mr. Mahaffey completed a draft of the detailed task analysis of the Difficult Airway decision tree. The task analysis information follows the description presented in the last quarterly progress report. An MS-Excel spreadsheet structure has been adopted to manage this information. The task analysis was conducted by interviewing the LOTAS group member (Dr. Dauphinee) who was primarily responsible for developing the decision tree. We are using the Difficult Airway scenario as a test case for developing our analytical procedure, from task analysis to MicroSAINT model to video analysis of an actual case. The task analysis information is now being reviewed by the LOTAS group as a whole. At question is the appropriate level of detail to strive for in such a task analytic process. We need to determine whether we can simply characterize the events during an actual Difficult Airway case obtained from video analysis, and then base the initial MicroSAINT model on the video analysis. After the LOTAS group's input, we will decide how to proceed with regard to the other existing decision trees. We will also pass along the Difficult Airway task analysis to ONR to illustrate the procedure that we adopt.

<u>Implementation of Video Analysis Workstation and Software</u>

Since the last quarter progress report, we took delivery of the Video Analysis Workstation hardware and software and familiarized ourselves with the OCS Tools software package from Triangle Research Collaborative (TRC). A schematic diagram of the system configuration is presented in Figure 1.

- the computer reads both visual (VITC) and audio (LTC) time code from the tapes.
- the user can control the VCR from the computer keyboard, searching the video tape either backwards or forwards at a range of speeds.
- observed events can be coded by pressing pre-selected keys on the computer keyboard; the system logs each event and associates it with a time stamp read from the time code stored on the tape; with each event the user may enter a textual comment of up to 240 characters; the event logs and associated information are entered into a data file that can be exported into Paradox or another data base management system.
- the event data file can be edited as the user makes interactive observations of the taped scenario.
- the tape can be played back with the events and associated information appearing as an overlay on the video monitor.

For Data Analysis there is a summary statistics system that analyzes data sets and calculates the frequency and duration of specific events. There is also an Interval analysis system that calculates the duration and frequency of specific events and the rate of occurrence of events within intervals. Time series comparison allows up to 8 comparisons using up to 8 different data sets. The Duration analysis system provides a time-line of consecutive events within a data set. The Pattern analysis system allows the user to specify a sequence of up to 10 codes within a data set and the system searches for all the occurrences of that exact sequence. In addition, physiological data can be analyzed in parallel with the video analysis data. This is possible because physiological data is collected simultaneously with the video and both stored on disc for off-loading to Paradox database management software and also overlaid on the video image. MicroSAINT predictions derived from analysis of clinical management algorithms are also stored on the AT&T PC386. Comparisons between measures derived from video analysis and those obtained from MicroSAINT predictions can therefore be made.

Implementation of a Process Model in MicroSAINT

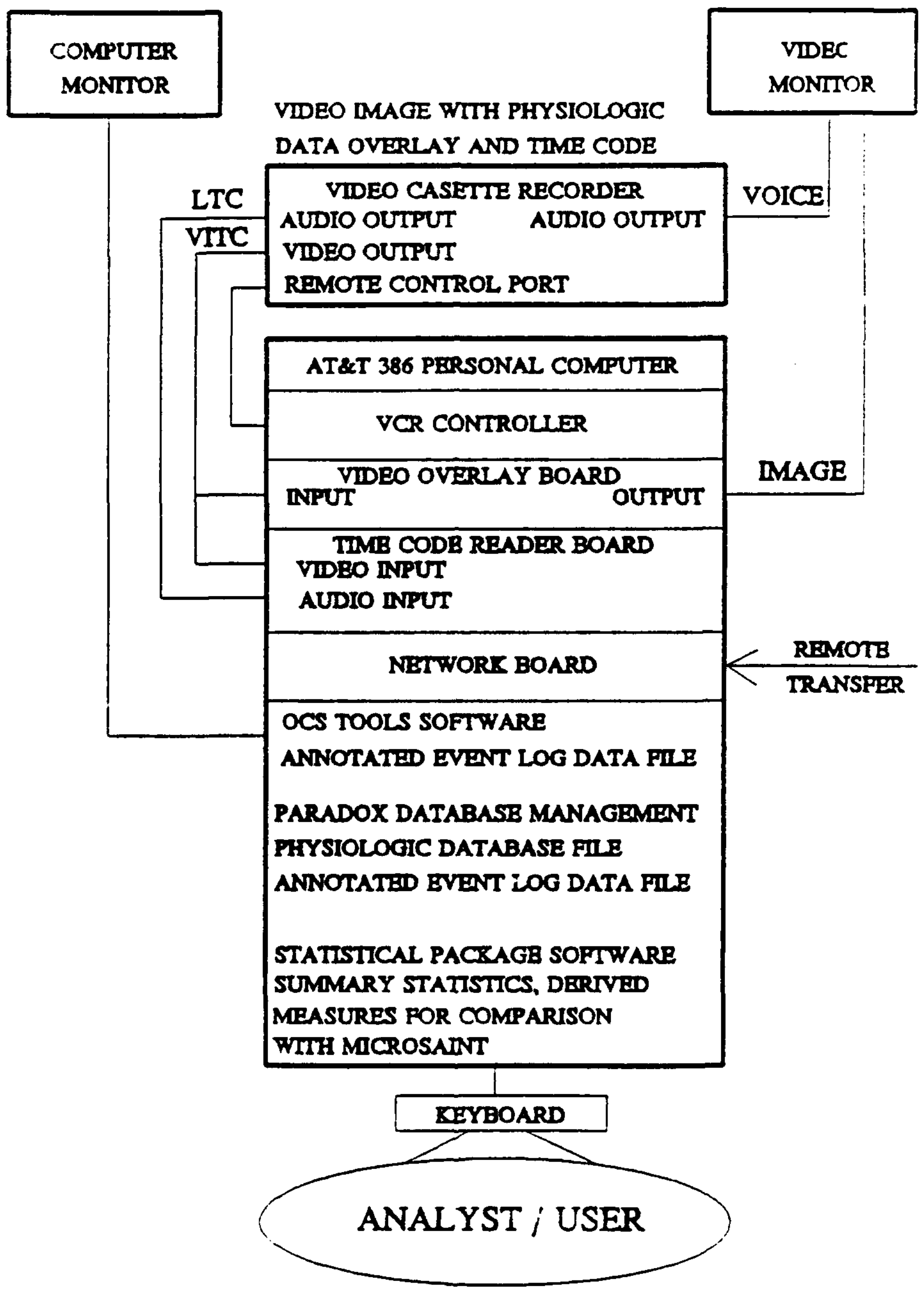
The Difficult Airway scenario task analysis is pending review by the LOTAS group. We will incorporate any suggestions that they may have and then translate this information into a MicroSAINT model. As additional decision trees are subjected to this task analysis procedure, we will likewise translate them into MicroSAINT models and develop a super-structure to account for the likelihood that during actual cases various decision trees may be simultaneously active.

Set-up and Programming of Video Taping Equipment

Video cameras are mounted in two admitting areas and video taping of six patient admissions has been completed. The PC's in the admitting area have been connected to the physiological monitors and physiological data overlayed on the video image. Fig. 2 is an updated schematic of the video and data acquisition equipment configuration. Details of the equipment are summarized in an abstract titled "Video Data Acquisition and Analysis System for Anesthesiology" and a list of vendors, model numbers and prices enclosed with this report as Appendix #1. We believe this information may be useful to other researchers.

Fig. 1

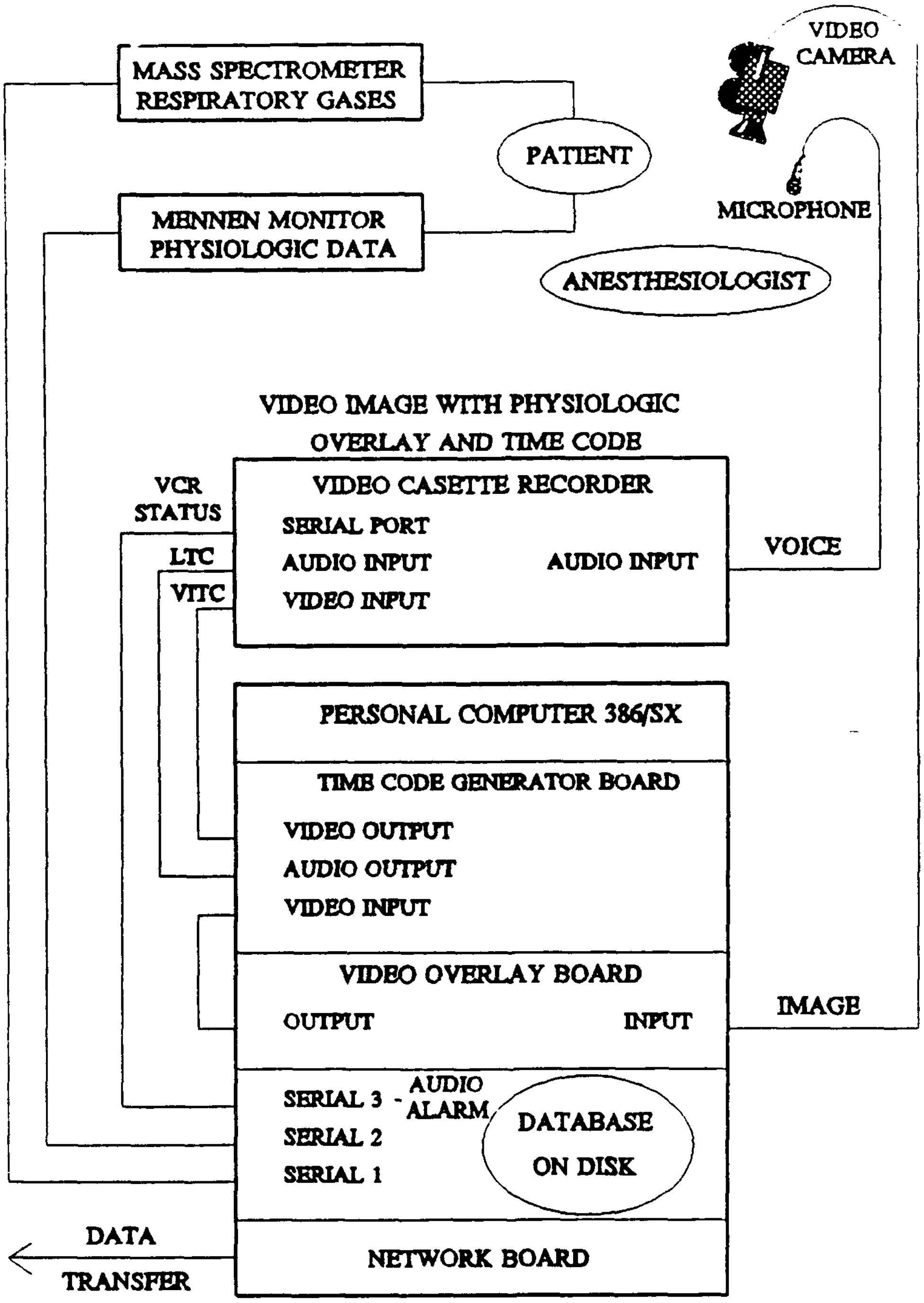
VIDEO DATA ANALYSIS SYSTEM



Some initial difficulties in using parts of the package were resolved in conjunction with Ted Szostak of TRC. In order to exercise the package and develop a procedure that is appropriate for our research interests, we have begun to analyze segments of the first video recordings obtained in Shock Trauma. In that these recordings were made prior to the time code generator board being installed in the data acquisition system, we first used OCS Tools to write machine readable time code onto these tapes. Subsequently, we have now successfully demonstrated the following capabilities of the package:

Fig. 2

VIDEO DATA ACQUISITION SYSTEM



From the outset, we have strived to make the video taping as unobtrusive as possible, both because we want the scenarios taped to be as representative as possible of typical anesthesiologist behavior and because we wanted to avoid further burdening the on-site personnel with having to operate the video equipment. Towards this end, several significant enhancements to the data acquisition system have been achieved in the quarter just completed:

- We selected a VCR (JVC-BRS6500) that supports a serial port and incorporated code in our program to query the status of the VCR. Through the serial port the VCR can now inform our data acquisition computer when the recording tape has run out and when a new tape has been loaded. The computer sounds a distinctive audible alarm when the tape needs to be changed.

- The data acquisition system now operates in a largely turn-key mode. Upon power up, the system waits for insertion of a tape, then writes a time/date stamp on the video image with the video overlay capability, then starts laying down both VITC and LTC time code based on an elapsed time clock. If additional tapes are needed for a given patient, the system will detect the end-of-tape, sound an alarm, and time the interval until a new tape is inserted. If more than 30 minutes elapses before insertion of the new tape, the system assumes that a new a patient has been admitted and resets the time code clock. If less than 30 minutes elapses, the system assumes that the new tape is a continuation of the same case and continues accumulating elapsed time.

- The data acquisition systems will typically remain powered up at all times. We are implementing a means to remotely access these systems from our lab and off-load the physiological data files stored on disk via the campus-wide data network. This will further reduce the extent to which we need to intervene in the day-to-day activities in Shock Trauma.

- The data acquisition systems have been outfitted with VGA graphics boards but will not typically have a monitor attached. Given the turn-key mode of operation, there is likewise no need for a keyboard. Therefore, these systems will function without being a distraction to the on-site personnel. The only way in which the staff will interact with these systems is in loading a new tape upon being prompted by the computer alarm, and in depositing the recorded tapes in a locked box from which they will be periodically collected and logged into the Shock Trauma QA system. For the occasional instances when project personnel will need to troubleshoot or otherwise access the data acquisition systems by other than remote means, we will have a cart available with VGA monitor, keyboard, and other test equipment.

Recording of Trauma Treatment Scenarios

Segments showing initial treatment of six trauma patients have been video taped in the Admitting Area. These segments will be used to further refine our data analysis procedures. Informed consent has been obtained from most of the Shock Trauma anesthesiology staff, and more extensive taping, on a routine basis, will begin soon.

Analysis of Video Tapes

A draft protocol has been developed for initial coding and analysis of the video tapes and has been submitted to the LOTAS group for their comments. The OCS Tools software is quite flexible and can run with a number of different video equipment configurations. We have identified the relevant software features that pertain to our research interests, and the sections of the documentation that pertain to these features. The draft protocol summarizes these procedures, and establishes an initial set of event codes (i.e., anesthesiologist behaviors) by which the taped scenarios will be characterized. The intent is to ensure that the various investigators who will be analyzing tapes, and the anesthesiologists who will assist as "subject matter experts," are all following a common set of documented procedures. These procedures will, no doubt, be revised and enhanced as we gain experience with video analysis. The draft protocol will be passed along to ONR after any revisions suggested by the LOTAS group have been incorporated. We have abstracted possible approaches to identifying stressors from material supplied by Dr. David Gaba a consultant and also from material provided from an unknown source at the Department of the Navy, Naval Training Systems Center, 12350 Research Parkway, Orlando Florida 32826. We were most grateful to receive 14 documents from this source covering areas including personality and group performance, team training and performance, decision making in the real world and under stress.

The AT&T PC 386 (shown in Fig. 1) contains the following hardware: a) VCR controller board which allows the operator to control the VCR from the PC keyboard. b) Video time code system which allows VCR synchronization and automatic collection of time from the video tape. The VITC interface reads frame time at play speed and slower including freeze frame (paused) operation. c) Recordable video-overlay (RVO) system which enables the user to view video images and computer generated information, such as time signals, digital physiological data and textual comments, simultaneously on one video monitor. RVO also allows video tapes to be made of the analysis that can be used to train analyzers or for demonstrations.

Fatigue Assessment and NEO-Personality Inventory

From Dr. Timothy Elsmore at the Office of Military Performance Assessment Technology (OMPAT) we have acquired software that creates a synthetic work environment and can be used to assess fatigue. We have introduced trauma and non-trauma anesthesiologists to this software. According to Dr. Elsmore's publications, users will typically need about 7-10 training sessions to reach asymptotic performance. We hope to have completed the training process in enough trauma anesthesiologists by March to allow this assessment to be used to quantitate fatigue.

The NEO-Personality Inventory measures five factors, neuroticism, extraversion, openness to experience, agreeableness and conscientiousness and provides a general description of normal personality. The computerized version administers, scores and interprets the 243-item (including 3 validity items) of the NEO-Personality Inventory within 45 minutes. Stability coefficients ranging from 0.51 to 0.83 have been found in 3, 6 and 7 year longitudinal studies. The Inventory has been validated against other personality inventories and projective techniques. We have introduced trauma and non-trauma anesthesiology personnel to this personality questionnaire with circulated material. We plan to begin administration of the Inventory shortly.

Personnel and Administration Matters

Peter Hu replaces Xun Luo on ONR funding at the same % effort and salary, starting from January 1, 1992. Mr. Hu has a B.S. in electrical engineering and an M.S. in computer science. He is an expert at computer networks and database management. He has worked at the University of Maryland for the past 3 years in another department. Mr. Hu has a lot of useful contacts on the campus that will greatly facilitate the accomplishment of the objectives of this ONR grant.

The implementation of the video analysis system, purchase of computer-compatible equipment and fulfillment of hospital electrical safety requirements for the video and computer systems has required more time than anticipated. The OCS Tools video analysis software required return to the vendor for reconfiguration as certain essential drivers were omitted from the copy we received. In addition difficulties occurred because OCS Tools runs on the MS-DOS 3.3 operating system whereas we are using MS-DOS 5.0. We feel that all the major hurdles have now been overcome. Acquisition and analysis of video tapes will begin in earnest in the 4th quarter.

Publications

Enclosed in Appendix #1 is an abstract that will be submitted to the 5th International Trauma Anesthesia and Critical Care Society (ITACCS) Meeting.

In Appendix #2 is a book chapter written by the PI for inclusion in the "Textbook of Trauma Anesthesia and Critical Care." Pages 10-12 describe the ONR project. There is also some MicroSAINT modeling shown. In addition to these publications, the Task Analysis Survey information is being collated and will be presented at the 5th ITACCS meeting. The analysis of eighty-two completed surveys are currently nearing completion. The authors of this survey are Doctors Jerry Nolan and Michael Parr, both member of the LOTAS group.

APPENDIX #1

VIDEO DATA ACQUISITION AND ANALYSIS SYSTEM FOR ANESTHESIOLOGY

C.F. Mackenzie*, R. Horst+, R. Moorman*, D. Smith+, P. Hu*, J. Brown° and LOTAS*°

Performance of anesthesiologists in the clinical environment has been judged on the basis of peer review, subjective observation, data from mortality and morbidity conferences, case reports and examination of closed claim insurance studies. There is very little behavioral data available on anesthesiologists' performance under stress, because critical incidents in anesthesia are rare, unpredictable, and inadequately documented. During trauma patient resuscitation and anesthesia there are a higher than usual number of critical events. In order to study anesthesiologists in this environment we configured a video data acquisition and analysis system.

Because the efficacy of treatment for trauma patients depends heavily on restoration of abnormal physiological parameters to normal ranges, we interfaced outputs from physiological monitors to the video data acquisition system. A personal computer (Everex PC386/SX) acquired physiological data through serial ports (RS232) from an eight channel monitor (Mennen model 2200) and mass spectrometer (Med Spec II) connected to the patient. The PC also supported 1) a time-code generator (Adrienne Electronics) writing machine readable time code onto a video cassette recorder (VCR, JVC BRS605), 2) a video overlay processor (Aitech International) which displayed digital physiological variables on the video image recorded from a ceiling-mounted video camera (Panasonic GPKR402) and microphone (Shure SM57-CN), 3) a serial port to sense the status of the VCR (e.g start, running, tape end), and 4) a network board for remote control and off-loading data.

Videoanalysis used a PC386 AT&T with a time code reader (Adrienne Electronics), VCR controller (Triangle Research Collaborative (TRC) and video overlay processor (US Video) in addition to a VCR (JVC-BT7700) and video monitor. Observational analysis of the videos was supported by OCS Tools Software (TRC) and allowed frame-accurate control of the VCR by time code. Anesthesiologists behaviors can be coded by single keys or by logging of time-stamped textual comments about the scene being viewed. The resulting observational data file was quantified by summary statistics and related to the corresponding physiological data using Paradox database software.

This system facilitates exploratory data analysis because of its flexibility, ease of use, and both interactive and analytic strengths. Other investigators have filmed physiological monitors with a second camera and viewed the scenario and monitors simultaneously but without interfacing. The configuration described has the advantage of requiring only one camera and allowing critical points in treatment to be rapidly located for detailed videoanalysis by automatically scanning the physiological database for time intervals when these parameters were abnormal.

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APPENDIX #1

Video Data Acquisition and Analysis System Equipment

Vendor	Item	Model #	Unit Cost
CTL Video	VCR	JVC BRS605-U	1725.00
9301 Georgia Ave.	serial port module for VCR		305.00
Silver Spring, MD 20910			
(301) 585-6311			
Pierce Phelps Co.	video color monitor (Sony)	PVM1380	330.00
7-7 Metropolitan Court			
Gaithersburg, MD 20878			
(301) 948-5266			
Newark Electronics	low leakage-isolation transformer	46F2196N-92-MD	221.48
12113 Indian Creek Ct.			
Beltsville, MD 20705-1238			
(301) 604-1700			
Industrial Vision Source	industrial camera color 1/2" (Panasonic)	GP-KR402	1280.00
1220 Champion Circle	6mm A/I lense 1/2" CS mount		197.86
Suite 100	cable BNC to BNC 100'		30.00
Carrollton, TX 75006	transformer power supplies		10.00
(800) 627-6734	camera 24VAC 1/2" CCD color (Toshiba)	IK-632A	575.00
	6mm fl.2 A/I lens 1/2" format	HAS0612APC	197.86
Triangle Research and Collaborative, Inc.	OCS Tools software		3700.00
P.O. Box 12167	Time code reader/generator/translator board & software	PC-VLTC/RG1	1945.00
Research Triangle Pk, NC 27709	OCS playback software		450.00
(919) 549-9093	Recordable video overlay hardware/software		1245.00
	VCR controller hardware/software		975.00
	VCR (w/dual audio capability to add time base correction at a later date; modified for compatibility with OCS Tools drivers)	JVC-BT7700-U	2560.00
	NTSC video monitor		345.00
AITech International Corp.	Pro VGA/TV video overlay board w/video titler		506.95
830 Hillview Ct., Suite 145			
Milpitas, CA 95035			
(408) 948-3291			
Qualified Systems Support	Everex personal computer w/40 MB hard drive, VGA card, 2 MB RAM, 1.2 MB floppy disk drive, DOS 5.0 operating system	Tempo 386/SX-16 MHz system	1554.00
1321C Mercedes Drive			
Hanover, MD 21076			
(301) 859-1003			

Adrienne Electronics 11994 Majon Drive Nevada City, CA 95959 (301) 644-2005	Time code generator board		517.00
Shure Brothers Inc. 222 Hartney Ave. Evanston, Ill 60202	Microphone (undirectional)	SM57-CN	140.00
3Com or **Western Digital**	Network interface card	Etherlink II Ether card plus	170.00
Panasonic	camera mount		68.00

Simulation of Trauma Anesthesia

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The uses of anesthesia simulators and training devices are multiple and include training in basic anesthesia skills, teaching of complex problems, testing of new equipment and assessing human factors in anesthesia. This chapter describes present and future possibilities for simulation specifically in the field of trauma anesthesia. The chapter starts by briefly describing where stat-of-the-art of trauma anesthesia is practiced, why trauma anesthesia is different and how simulation could be particularly useful for training and research in trauma anesthesia. The middle portion of the chapter discusses existing simulators and training devices relevant to trauma anesthesia. The latter part of the chapter describes video analysis of trauma anesthesia and the possible benefits of this approach to development of simulations and training strategies relevant to trauma anesthesia.

State-of-the-art trauma anesthesia

Data from Maryland, Illinois and California suggest that fatalities can be prevented by implementation of regional trauma systems.[1-7] Potentially salvageable patients were more likely to die in non-trauma than trauma facilities.[4-7] In one study 25% of fatalities and 16% of all injuries were considered inappropriate for the severity of injury incurred.[5] In addition, these investigators found that hospitals with less than 200 beds had a higher % of early deaths from trauma than large hospitals. Following implementation of regional level one trauma centers the age, and the injury severity score of those dying was higher, confirming that those patients with lower scores that previously had died were now living.[6]

The rate of deaths from injuries occurring before patients reached a medical facility in the rest of the U.S. averaged 2.5 times more than occurred in Maryland.[8] Analysis of the pattern of mortality according to the location of death in Maryland at the Maryland Institute for Emergency Medical Systems (MIEMSS) shows that consistently over the past 15 years roughly 10% of the deaths were dead on arrival (DOA) or were declared dead within 30 minutes after resuscitation was unsuccessful. Despite this consistency of DOA and Maryland having a much higher successful delivery rate of trauma patients to medical care, the deaths occurring in the operating room (OR) while patients are anesthetized and the survival rate for the first 24 hours have both improved. Deaths occurring in the OR as a % of early deaths 1978-1987 are shown in Fig. 1 and have fallen from 36% in 1978 to 16% in 1987. Similarly survival for the first 24 hours occurred in all but 10% of admissions in 1970-1972 and it has approximately doubled to all but 5.5% of admissions in 1986-1987 (Fig. 2). The injury severity score (ISS, see Chapter 4) data between 1980 and 1987 show that the improvement in care has taken place despite the admission of a greater number of more seriously injured patients (Fig. 3). These data strongly suggest that level one trauma center care and anesthesia have improved patient outcome. The above evidence suggests that the practice of trauma anesthesia at level one trauma centers is likely to reflect state of the art trauma anesthesia management.

	1980	1986	1987
Early deaths Less than 24 hours	6.8% (96 pts)	4.8% (100 pts)	4.7% (99 pts)
Deaths after 24 hours	5.7% (108 pts)	5.2% (108 pts)	5.3% (113 pts)
ISS 20+	11.8% (119)	17.9% (322)*	15.7% (308)*
ISS 12-19	11.8% (119)	22.6% (420)	24.2% (476)$^{\circ}$
ISS less than 11	50.7% (512)$^{+}$	36.6% (679)	39.8%
(782)			

* $p<0.01$ 1987 and 1986 v 1980
o $p<0.01$ 1987 v 1980
\+ $p<0.01$ 1980 v 1986 and 1987

Fig. 3: Deaths occurring in less than 24 hrs (Early deaths) and more than 24 hrs after admission to MIEMSS , 1980-87. The % of patients (pts) with Injury Severity Scores above and below 20 is shown for each year. In 1986 and 1987 compared to 1980 there were a greater number of more severely injures patients admitted yet the early deaths as a % of the total admission fell.

Why is trauma anesthesia different?

Trauma anesthesia differs from every other kind of anesthesia in several important ways (see also Chapter 5). Firstly, it is difficult to obtain a medical history because the injured patient may be unconscious, unresponsive or under the influence of pharmacological agents including alcohol. No past medical history or old records are usually available in the emergency environment surrounding admission of recently traumatized patients. Since trauma is unique to each individual, the site and extent of injury is unknown and must be identified on admission to the medical facility. The traditional approach of taking a history, performing a physical examination, ordering some investigations and establishment of a diagnosis before starting anesthesia is clearly inappropriate in the management of the severely injured trauma patient. Priorities must be established to deal with the most rapidly fatal problems first.

Trauma anesthesia differs from other anesthetic practice because of the frequent need for emergency airway management under less than ideal circumstances such as when blood, vomit, bony fractures and foreign bodies obstruct the airway. In level one trauma anesthesia the majority of patients are often transported directly and rapidly by helicopter from the scene of injury and are hemodynamically unstable. Unlike many other forms of anesthesia the patient is acutely stressed and physiological compensatory mechanisms are activated to maintain cardiac filling and blood pressure despite hypovolemia. In these conditions anesthetic induction must occur before the patient is stabilized and during the resuscitative effort.

Identification of life-threatening trauma complications including pneumothorax, cervical spine and major vascular injury, lung and cerebral contusion all require specialized knowledge and management by the trauma anesthesiologist. Routine anesthesia practice, or even penetrating trauma associated with knife and handgun injuries, is inadequate preparation for management of anesthesia involving multiple system injuries received from high velocity missiles, blunt trauma due to explosions and high speed injuries.[9] There is no rapid and efficient way currently available to disseminate the important management considerations required by a trauma anesthesiologist. Presently trauma anesthesia management is taught by time consuming clinical rotations through level one trauma centers. These rotations are inefficient because they are both labor and facilities intensive, and provide clinical experiences dependent on the types of patients admitted during the clinical rotation.

Why is training of trauma anesthesiologists difficult?

There is a need to train more personnel in management of the critical life-threatening problems associated with anesthesia care for patients with major trauma. The shortage of trained personnel is a result of the limited availability of major trauma centers patients, and experts in anesthesia for trauma. As a result even the military anesthesia personnel receive training in level one trauma centers. Teaching of anesthesia for major trauma is limited by most hospitals having insufficient populations of severely traumatized patients to enable an adequate clinical experience during training. In trauma centers the occurrence of frequent trauma patient admissions at night and the weekend reduces the availability of faculty experts. The considerable seasonal fluctuation in trauma admissions (Figs. 4 and 5) means that one anesthesiology trainee may not be exposed to as many trauma critical events or patients as another. This may result in gaps in clinical experience during a fixed duration rotation.

How could simulation of trauma anesthesia help?

Simulation may correct the deficiencies in training of anesthesia personnel in managing life threatening events during trauma anesthesia. Simulation of anesthesia for trauma is efficient because it allows clinical training without risk to a patient and can be carried out in a non-clinical setting. State-of-the-art management is potentially available in a highly portable form that could be employed in every residency training program or in designated trauma anesthesia simulation centers. Intellectual, psychomotor, and decision making skills about management of traumatized patients can be learned without risk to patient safety. Teaching by simulation is rapid because it takes the difficult and infrequent case that requires years of experience to manage and compresses the learning process into a short period of intensive training. Students who use medical simulations are reported to have enhanced receptiveness to instruction and better retention of didactic material using computer rather than conventional teaching.[(10)] In other non medical fields, those trained on simulators have an improved comprehension of the subject in a shorter time and at lower costs than those trained in a conventional environment.[(11,12)]

Trauma anesthesia is a particularly attractive medical domain to simulate because unlike elective anesthesia there is a high likelihood of a critical events and death occurring. Of all patients admitted to Shock Trauma who subsequently die, 47% die within the first 24 hours, 10% within the first 30 minutes and 20% die during resuscitation.[(9)] In addition anesthesia is attractive for simulation because anesthesiology has a central management component which makes it easier to program simulations than for other medical specialties. There are defined limits (the start and end of the operation) when a number of major management alternatives must be made at once. There are a variety of management alternatives to consider with enough complexity to be challenging but sufficiently circumscribed to be practically dealt with and simulated. Although there may be leeway in choices among management options for trauma anesthesia there are also clear cut risks and benefits,[(13)] so that decision making is complex. The advantages of simulations include that they are self teaching, self paced, can be repeated as often as required and they record participants responses. Personnel requirements, the need for classroom, lecturer and in-service instruction is substantially reduced by simulation. Objective assessment of clinical performance for certification or continuing education is easily obtained. A "debriefing" after completion of the "anesthetic" allows the simulation participant to review their responses to critical events or if the session is videotaped to play back the tape on a video tape recorder. The correct management of critical incidents may be identified on playback as they occur.

What are the existing Anesthesia Simulators?

In 1968 pioneering work by Denson and Abrahmson resulted in a computer controlled anesthesia simulator (SIM I) that was used to teach intubation.[(14)] This simple device allowed for a planned increase in the difficulty of the problem to be solved. The benefits of this approach were thought to be that there was almost unlimited repetition of any phase of the procedure, participants proceeded at their own rate. More correctly such as a system as SIM I would be categorized as a training device since it is focussed on teaching one specific skill rather than a true simulator that mimics the entire environment and patient.[15]

More recent simulators include those by Gaba and DeAnda (1988)[11,16,17] that recreates the operating rooms for research and training (Comprehensive Anesthesia Simulation Environment, CASE). Good, et al (1988) describe simulation of mechanical critical events in the anesthesia machine, its gas supply and breathing circuits using the Gainesville Anesthesia Simulator (GAS).[15,18] Schwid (1987), likens his Anesthesia-Simulator Recorder (called SIMCORD) to a flight simulator for general anesthesia training.[12,19] Pharmacological models simulating uptake and distribution include those of Phillip (GASMAN)[20], Gas Uptake Simulation (GUS)[21] and Tanner et al (ANSIM).[22] Simulation of cardiovascular responses to drug administration was described by Masuzawa et al[23] and is incorporated into SLEEPER, a multi-compartment pharmacological and physiological simulator. Mathematical models of Smith describing uptake and distribution of anesthetic agents and an early version of the simulator for general anesthesia are also included in SLEEPER.[23-27] The original descriptions of the Fukui/Smith model appeared in the proceedings of the 1972 San Diego Biomedical Symposium.[24]

Using CASE, Gaba and DeAnda have simulated life threatening critical airways events and cardiac rhythm disturbances.[28] They also have described non-life threatening issues including hypothermia, and vascular line failure. They further studied the responses of 19 anesthesiology residents to 5 simulated critical events: 1) endobronchial intubation 2) kinked intravenous (iv) infusion line 3) atrial fibrillation with hypotension 4) breathing tube disconnection, and 5) cardiac arrest. Simulations were videotaped and response times for detecting and initiating correction of the problems were measured.

Different problems had significantly different response tines. Breathing tube disconnect and cardiac arrest are quickly detected (21 ± 17 sec and 7 ± 5 sec) but in 58% of cases there were major management errors. Endobronchial intubation and atrial fibrillation took 105 ± 142 sec and 111 ± 158 sec to correct respectively. The Gaba and DeAnda simulator requires hand inflation of a balloon in the airway to simulate endobronchial intubation and manual kinking of the IV catheters. The response of individuals was highly variable. Experience was a significant factor for correction. Factors which led to delay or failure in problem handling were 1) disbelief of monitored data 2) failure to observe or utilize redundant data 3) a desire to avoid interruption of surgery 4) treatment of the usual cause of a problem rather than the true cause. In other papers Gaba has identified the role of experience[29] and looked at unplanned incidents during use of CASE.[30] Gaba and his group have published several studies that are of interest to trauma anesthesiologists.[11,16,17,28,31] In addition, the proceedings of the 1991 Conference of Human Error in Anesthesia, chaired by Gaba, provide a wealth of information of relevance to trauma anesthesia.[31]

CASE does not contain any pharmacological modeling so there is no computer modelled relationship between drugs given and responses shown on the monitors. Physiological data changes are operator-driven using a predefined script. A coordinator and computer analyst are required to produce the simulations. The SIMCORD simulator is developed from work done when Schwid was a resident with Smith and there are similarities between the SIMCORD and SLEEPER graphics. Both simulations test cognitive skills effectively and are relatively easy to operate as they are menu and mouse driven. No operator or coordinator is required. Mathematical models of physiology and pharmacology are used to predict responses to anesthetic and other drugs and to pathological changes. SLEEPER has sixteen compartments and can simulate blood loss from any organ such as liver, brain, kidney or from limbs. Computer screen simulations of the patient, anesthesia machine and physiological data can be used to "give an anesthetic". The SLEEPER and SIMCORD simulations includes several different types of patients, and a consultant expert is provided to explain physiological and pharmacological information. In SIMCORD a critique is also provided at the end of the simulation session. SIMCORD is available free through Janssen Pharmaceutica, Inc representatives since Schwid sold that company the rights for distribution.

Computer models, rather than true simulators, are in abundance. Pharmacokinetics and pharmacodynamics of anesthetic drugs may be modelled,[32-34] uptake and distribution of inhaled anesthetics,[20,21,27,30,35] onset and duration of neuromuscular blockade[33,34] and cardiorespiratory physiology[36-39] and other physiological interactions are well described by computer models and simulations.[40-44] All these may be useful training tools for trauma anesthesiologists.

What are the Concepts of Simulation?

There are several approaches to trauma anesthesia simulation including a) whole body computer models incorporating multiple physiological and pharmacological models, b) mechanical models incorporating the technology used for trauma anesthesia, c) models that recreate the trauma operating room environment and produce realistic trauma anesthesia critical events, and d) models developed from direct observation or videoanalysis of real trauma anesthesia.

Computer Models

At a minimum a useful computer model for trauma anesthesia must incorporate the heart, lungs, circulation and blood elements, nervous system, skin, muscles, liver and other gastro-intestinal organs and kidneys. There are three levels of computer models necessary for the physiological and pharmacological simulations.

1) *Whole body models*

Multiple compartment transport architecture[24,25,39] allows physiological functions and pharmacological actions and interactions to be modeled. The physiology model may center around a cardiovascular module, consisting of a beating heart (atria and ventricles); blood to transport gases, ions, chemicals, drugs, etc; and compartments, such as the brain, heart, and liver.

As an example, SLEEPER is a 16-compartment multiple transport model including the lungs, brain, liver, kidneys, heart and circulation. Within each compartment (heart, and in particular brain) is a series of receptor compartments, each for a different agent. Each receptor compartment contains a concentration/effect relationship, for example, concentration versus neuromuscular blocking effect. Since the model is a transport model, it can carry anything in the lungs and blood to the various compartments, and thence into and out of these compartments. In particular, it can transport information, fluids, gases, inhaled agents, and drugs via any route (intravenous, intramuscular, subcutaneous, lungs and skin), ions (including Ph), hormones, dyes, tracers and markers. By transporting H^+ and HCO_3^-, for example, Ph can be effected or implemented and transported, and acid-based physiology can be implemented. (Smith NT personal communication 1989)

Substances transported such as glucose or oxygen can participate in cellular function, or carry only information to control a specific action, as do hormones. The transport can be more than merely in the blood; it can be on protein or hemoglobin, with binding related to pH, protein species and concentration, and affected by the presence of other drugs. Since this is a multiple model system, any number of transportable elements can be added. As well as models for the lungs, heart and circulation, the following agents may be transported: oxygen, carbon dioxide, halothane, thiopental, fentanyl, and succinylcholine. The original SLEEPER model was implemented on a hybrid computer, it is now converted to an all-digital form. The models described in references[24-26] have undergone considerable expansion in more recent years (Smith NT personal communication 1989).

2) *Models for individual body systems*

The advantage of a very general structure in the whole body model is that it is amenable to addition of new drugs and embellishment of physiological detail. It may contain points of attachment for a wide range of subsystems which permit the addition of existing models generated by others. Many such useful subsystems component models exist. For example, a very complex and detailed model of heart metabolism has been constructed.[40] Other detailed subsystem simulation models include the renal[41] system, respiratory system,[42] thermoregulatory system,[43] nerve conduction system,[44] gastrointestinal system[45] and many other subsystems or components of subsystems. Individually, such models have provided additional insights into complex organ interactions and functions. However, important whole body organ system interactions are ignored by these separate subsystem simulations. By attaching the subsystem models to a whole body model there is a cohesive integration of these components into the overall simulated system. (Smith NT personal communication 1989)

3) *Integration of subsystem models*

Efforts to integrate very detailed subsystem models into an overall system has been limited, in part, by computing technology. Testing of such models during their development requires very substantial numbers of computer runs. Advanced statistical techniques are required to guide the testing and assimilate the resulting volumes of data. High-speed computing and parallel processing, may enable the computation of comprehensive systems with detailed submodels in the near future.

Use of simulators and training devices in trauma anesthesia

There are several different types of simulators and training devices used in anesthesia that may be useful for teaching various aspects of trauma anesthesia. For many years tracheal intubation models have been available. Gaba has recently added simulated vomitus to the challenge of securing such an airway[11]. Broken dental bridges and other foreign bodies can also be inserted to assess the anesthesiologist's ability to deal with the additional task of using tracheal suction or Magill forceps before tracheal intubation. Models are available to practice bronchoscopy. Simulated blood or other airway foreign bodies can be added to reproduce the difficult circumstances which may occur while securing the airway of the trauma patient.

Animal models may more realistically simulate tracheal intubation than a plastic model. For many years intubation of kittens was used to enable practitioners to practice intubation of the neonate. The larynx and tracheal dimensions are very similar in the kitten and neonate. Emergency cricothyroidotomy can be practiced on animals with monitoring of arterial O_2 saturation by pulse oximetry and CO_2 using mass spectrometry or an infra-red CO_2 analyzer. Pneumothorax and pericardial tamponade can be induced and relieved in animals. Subclavian intravenous catheter insertion can be practiced on many mannequins used for cardiopulmonary resuscitation. A model arm can be used to practice peripheral intravenous and radial artery cannula insertion.

Comprehensive anesthesia simulators such as the GAS incorporate a simulated patient and an anesthesia machine and monitors. The simulated patient breathes spontaneously, responds to peripheral nerve stimulation, produces appropriate inhaled and exhaled respiratory gases and anesthetic concentrations as determined by settings on the anesthesia machine flow meters and vaporizers. The anesthesia machine has several mechanical faults that can be activated to produce a faulty expiratory valve on the absorber circuit, leaks in the respiratory gas supply and many other possible equipment related critical events. Simulated critical events can be programmed to produce the appropriate changes in physiological data displayed on the patient monitors. GAS began primarily as a simulator of anesthesia machine faults but it has now evolved into a trainer for teaching residents basic skills and to allow management of simulated crises.

The CASE simulator recreates the operating room environment and is used for anesthesia crisis resource management (ACRM). The concept of ACRM is modelled on the cockpit resource management training employed by airlines who train and recertify pilots in cockpit simulators. CASE includes the entire operating room staff of nurses, surgeons, and anesthesia technicians because team coordination like crew coordination on an airplane is a key element of ACRM training. Teaching interaction and leadership, communication, distribution of workload, monitoring and cross-checking are all practiced and perfected in several ACRM scenarios (Fig.

6). The available resources are activated and the team is managed by the anesthesiologist participating in the simulations which include tension pneumothorax, and malignant hyperthermia.

Unfortunately, none of these simulators covers the entire spectrum of trauma anesthesia. The major deficiency in all of them is the patient. The response of the individual to a given intervention, the spectrum of different sites and types of injury, the constellation of multiple physiological disturbances that are potentially possible in a trauma patient cannot be simulated. However, one of the major advantages of simulators over the real thing is that rare events can be reduplicated. Individuals can be tested in identical circumstances so that performance can be better judged between trainees.

Video analysis of trauma anesthesia

Single factors rarely cause accidents - rather accidents develop through multiples of factors each insufficient to create an incident (Fig. 7). Studies of human performance in other complex environments suggests parallel assessments of performance could be made by observation of anesthesiologists. However, critical incidents that stress performance are rare unpredictable and usually inadequately documented. Realistic simulations have been proposed as a means for understanding the human role during incident evolution, but these techniques depend critically on the scenarios chosen for simulation[46] and the "patient" is not realistic. Examination of data on bad outcomes from mortality and morbidity conferences, case reports and closed claim studies are useful in describing what went wrong. However, they are rarely of help in identifying human performance issues as to why it went wrong. Because there is a high likelihood of a critical incident occurring during trauma resuscitation and anesthesia, direct observation and analysis of performance may provide prospective evidence of cognitive skills and performance in a real life stressful environment. During trauma anesthesia and resuscitation, dynamic decision making occurs, often under time pressures and other stressors. A group of anesthesiologists at the University of Maryland and MIEMSS have recently been funded by the Office of Naval Research to review video tapes taken in the Shock Trauma Center admitting areas and operating rooms.[(9)] Videoanalysis will attempt to identify stressors in this environment that may affect performance including, fatigue, team interactions, time pressures, workload issues. As a start to the project the group of investigators who call themselves the LOTAS Group* (acronym derived from Level One Trauma Anesthesia Simulators) developed decision trees for interventions required when physiological variables became abnormal. Therefore, algorithms for management of hypotension, hypertension, bradycardia, tachycardia, hypothermia, hyperthermia, elevated end-tidal O_2, decreased end-tidal CO_2 and hypoxemia were developed. One of the aims of the video analysis will be to compare the decision trees to what actually happens in real-life and iteratively improve the decision trees. This may lead to development of a trauma anesthesia emergency procedure manual.

A second part of the decision tree development involves modelling using a human factors software package (MicroSAINT) that has been extensively used by the military to model decision trees. For example, taking the American Society of Anesthesiologists (ASA) decision tree for management of the difficult airway we can divide it into 5 possible pathways designated 0, 1-4 on Fig. 8. Pathway 0 is undefined by the other 4 and may encompass portions from each of the other pathways. Decisions are shown as diamonds and actions as rectangles on the tree. Times for completion of the decision making and actions are shown hand written on the decision tree. These times are guesses but following measurement of such videotaped scenarios, real times could be inserted. Iteration of MicroSAINT 1000 times (takes about 8 mins on a 386 PC) gives a frequency distribution of execution times including all routes (Fig. 9). How often each of the 5 routes was chosen to achieve tracheal intubation can be determined (Fig. 10) and, in this particular simulation, route #2, which involved percutaneous cricothyroidotomy jet ventilation, was the commonest single route. Time to completion of any of the routes is also derived (Fig. 11) Route #1 was generally fastest as it is the only one of the 5 routes that is able to achieve intubation rapidly. Route #1 is the traditional approach in which there is a difficult airway that can be mask ventilated, and the chosen technique is successful at the first attempt. With such modelling, the affects of adding an additional anesthesiologist, of using one approach compared to another, and identification of bottle-necks in the process of reversing an abnormal physiological state can be determined.

The equipment includes fixed miniature video cameras and microphones which are interfaced with a video cassette recorder and a PC 386 (Fig. 12). The computer contains two additional boards, a video overlay board (VOB) and a time code generator. Physiological data from patient monitors are captured at 5 sec intervals through serial ports (RS422) and these are imprinted on the videotape by means of the video overlay board. Data captured includes heart rate, systemic and venous blood pressures, mass spectrometer data, arterial O_2 saturation and temperature. Decision making in trauma resuscitation and anesthesia is closely related to changes in such physiological data. When the patients vital signs identified above vary from prescribed acceptable limits the anesthesiologist instigates an investigation of the cause, then an intervention to reverse the cause and in order to return the physiological parameter to normality. The LOTAS Group intends to identify cognitive skills displayed in these video tapes by means of video analysis using OCS Tools software (Triangle Research, Durham, N.C.).

Analysis of the videotapes will be carried out by trauma anesthesiologists and experimental psychologists (Fig. 13). They will make independent judgements of workload, the appropriateness of the treatment teams actions at various critical junctures. Assessment of patient severity of injury will use the ISS scoring system and anatomic index. Anesthetic risk will be assessed by the ASA classification system and another more complex classification devised strictly for trauma anesthesia. Subjective data will also be collected from the anesthesiologists who are videotaped. Consultation with the anesthesiologist who was videotaped will be available to interpret events that may not be immediately obvious on videotape. Subjective data will also be collected from the anesthesiology team regarding their perceptions of how stressful the anesthetic management was, their experience with similar patients, their impression of the team interactions and so forth so that we will have subjective impressions of the anesthesiology team that can be compared to the videoanalysis data. The effects of various stressors such as fatigue, workload, team interactions in sharing and shedding tasks and physician experience need to be investigated in the trauma anesthesia environment.

Basic questions about stress remain unanswered such as the extent to which different stressors alone and in combination affect time-critical performance and decision making. What cognitive skills are needed for successful decision making under stress. How do the differences between individuals interact with task requirements in determining outcome?[9] What training strategies are most effective in preparing decision makers for the moment of crisis? It is difficult if not impossible to adequately study performance and decision making under stress in contrived laboratory settings. On the other hand, the study of performance under stress in a real-life setting is also difficult. The use of trauma anesthesia as a model seems highly appropriate. At the Shock Trauma Center about 70% of the approximately 4,000 patients that are admitted per year to this Level One Trauma Center arrive by helicopter directly from their scene of trauma. Of all the patients that die following admission 47% die in the first 24 hrs, 10% in the first 30 min and 20% during resuscitation.[47] There is, therefore, the scenario to create stress in a real-life setting.

Video analysis is a way that important coping mechanisms or strategies used by the expert trauma anesthesiologist can be identified. These strategies may be helpful in the training of others. Video analysis may identify factors that affect cognitive skills and procedures necessary for decision making under stress. The MicroSAINT modeling may generate ideas that are applicable in other less stressful environments such as elective anesthesia, other medical and non-medical specialties. Observation of a real-life setting and analysis in detail of that setting will of course be an excellent platform from which simulations may be developed and training strategies determined.

Future uses and validation of simulation

Many of these simulations, simulators and training devices described in this chapter may be used to assist teaching of trauma anesthesia in a non-clinical environment. Commercial anesthesia simulators that recreate the operating room or resuscitation area environment are a future possibility. The most viable efforts towards this end are those of Gaba (CASE) and Good (GAS). The crisis resource management course designed by Gaba clearly lays the ground work for using such a simulated environment to assess cognitive psychomotor and leadership skills of anesthesiologists. The computer simulation of Schwid is commercially available and is an effective way of teaching and assessing cognitive skills. The time is, therefore, close when we should expect such simulations to be used for training, certification and recertification of anesthesiologists. It is predictable that trauma anesthesia will be an important component in these simulations and simulators because of the likelihood of critical events and the uncertainty surrounding diagnosis in trauma anesthesia management.

Whether or not simulators can be scientifically shown to be of benefit is questionable. Trauma anesthesia simulations may be shown to be equally good as clinical rotation through a Level One Trauma Center. Will use of simulators make trauma anesthesia safer and trauma anesthesiologists more skillful? It is possible. It is certainly the case in aviation, the nuclear power industry and in navigation of supertankers that legislative bodies supervising such industries believe simulators maintain standards, improve safety and assist training and recertification.[12,15,31]

Summary

Simulators, training devices and computer models will all keep the chronic shortage of facilities for training trauma anesthesiologists. Because trauma anesthesia deals with a stressful environment decision making may be impaired by fatigue, work overload, team interactions, uncertainty, physician anxiety and time stressors. Many coping behaviors that expert trauma anesthesiologists implement could be taught using simulators. The concepts of team interaction could be fine tuned using simulators that recreate the trauma resuscitation environment. The end result of these computer applications to trauma anesthesia is intended to improve care for the trauma patient.

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References

1. Boyd D.R.: A symposium on the Illinois trauma program. A systems approach to the care of the critically injured. J. Trauma 12:275-276, 1973.

2. Cowley R.A.: Total emergency medical system for the State of Maryland. Md. State Med. J. 24:37-45, 1975.

3. Gill W., Champion H.R., Long W.B., et al: A clinical experience of multiple trauma in Maryland. Md. State Med. J. 25:55-58, 1976.

4. West J.G., Trunkey, D.D.. Lim R.C.: Sysyrm of Trauma Care. A Study of two countries. Arch Surg. 114:455-460, 1979.

5. Lowe D.K., Gatley H.L., Goss J.R., et al: Patterns of death, complication and error in the management of motor vehicle accident victims. Implication for a regional system of trauma care. J. Trauma 23:503-509, 1983.

6. Cales R.H.: Trauma mortality in Orange County: the effect of implementation of a regional trauma system. Ann Emerg. Med. 13:1-10, 1984.

7. Wright C.S., McMurty R.Y., Pickard J.: A postmortem review of trauma mortalities,
a comparative study. J. Trauma 24:67-88, 1984.

8. Shock Trauma Annual Report Statistics 1987-1988.

9. Mackenzie C.F., Horst R. and the LOTAS Group: Proposal to ONR. Development and Enhancement of a model of performance and decision making under stress in a Real Life Setting. Funded by Grant # N0014-91-J-1540.

10. Hoffer E.P.: Experience with use of computer simulation models in medical education. Computer Biol. Med. 3:269-279, 1973.

11. Gaba D.M., DeAnda A.: A comprehensive anesthesia simulation environment, re-creating the operating room for research and training. Anesthesiology 69:387-394, 1988.

12. Schwid M.A.: A flight simulator for general anesthesia. Comp. and Biomed Res 20:64-75, 1987.

13. Miller P.L.: Critiquing Anesthetic Management. The ATTENDING Computer System. Anesthesiology 58:362-369, 1983.

14. Denson J.S., Abrahamson S.: A computer-controlled patient simulator. JAMA 208:504-508, 1969.

15. Good M.L., Gravenstein.: Anesthesia simulators and training devices. Int. Anesth. Clinics 27:161-166, 1989.

16. Gaba D.M.: Human Error in Anesthetic Mishaps. Int Anesthesiol Clinic 27:137-147, 1989.

17. Gaba D.M., Maxwell M.S., DeAnda A.: Anesthetic mishaps: Breaking the chain of accident evolution. Anesthesiology 66:670-676, 1987.

18. Good M.L., Lampofang S., Gibby G., Gravenstein J.S.: Critical events simulation for training in anesthesiology (abstract). J. Clin. Mont. 4, 140, 1988.

19. Schwid H.A., O'Donnell, D.: The anesthesia simulator-recorder: A device to train and evaluate anesthesiologists responses to critical incidents. Anesthesiology 72:191-197, 1990.

20. Phillips J.H.: Gasman: An example of a goal oriented computer assisted teaching which results in learning. Int J. Clin Monit. Comp. 3:165-173, 1986.

21. Gas uptake Simulation (GUS). User Reference Document # 18602062A Release 3.0 Phoenix, iMedId Inc, 1987

22. Tanner G.E., Angers D.G., VanEss E.M., Ward C.A.: ANSIM: an anesthesia simulator for the IBM PC. Comp. Meth and Prog in Biomed. 23:237-242, 1986.

23. Masuzawa T., Fukui J., Dohi T., Smith N.T.: Simulation model of cardiovascular response for drug administration. J. Clin Mont. 4:150, 1988.

24. Smith N.T., Zwart A., Beneken J.E.W.: An analog computer multiple model of the uptake and distribution of halothane. Proc San Diego Biomed Symp. 11:235-241, 1972.

25. Fukui Y., Smith N.T.: Interaction among ventilation, the circulation and the uptake and distribution of halothane. Use of a hybrid computer model 1. The basic model. Anesthesiology 54:107-118, 1981.

26. Schwid H.A., Wakeland C., Smith N.T.: A simulator for general anesthesia. Anesthesiology 65:A475, 1986.

27. Fukui Y., Smith T.: Interactions among ventilation, the circulation and the uptake and distribution of halothane - Use of a hybrid computer multiple model: II Spontaneous vs controlled ventilation and the effects of CO_2. Anesthesiology 54:119-124, 1981.

28. Gaba D.M., DeAnda A.: The response of anesthesia trainees to simulated critical incidents. Anesth. Analg 68:444-448, 1989.

29. DeAnda A., Gaba D.M.: The role of experience in response to simulated critical incidents. Anesth. Analg (In Press).

30. DeAnda A., Gaba D.M.: Unplanned incidents during comprehensive anesthesia simulation. Anesth. Analg 71:77-82, 1990.

31. Gaba D.M., Howard S.K.: Report of a Scientific Meeting. Anesthesiology 75:553-554, 1991.

32. Ebling W.F., Lee E.N., Stanski D.R.: Understanding pharmacokinetics and pharmacodynamics through computer simulation I. The Comparative clinical profiles of fentanyl and alfentanil. Anesthesiology 72:650-659, 1990.

33. Jaklitsch R.R., Westenkow D.R.: A simulation of neuromuscular function and heart rate during induction, maintenance and reversal of neuromuscular blockade. J. Clin Mont 6:24-38, 1990.

34. Sheiner L.B., Stanski D.R., Vozeh S., Miller R.D., Ham J.: Simultaneous modelling of pharmacokinetics and pharmacodynamics: Application to d-tubocurarine. Clin Pharmacol. Ther 25:358-371, 1979.

35. Leron G.C., Dirksen R., Kolmer H.H.B, Booij L.H.D.: A system model for closed circuit inhalational anesthesia I. Computer Study. Anesthesiology 75:345-355, 1991.

36. Guyton A.C., Coleman T.G., Granger H.J.: Circulation: Overall regulation. Ann Rev. Physiol. 34:13-46, 1972.

37. Sunagawa K, Sagawa K: Models of ventricular contraction based on time varying elastance CRC. Crit Rev in Biom Eng 7:193-228,1982.

38. Lockwood G.G., White D.Z.: Effect of ventilation and cardiac output on the uptake of anesthetic agents from different breathing systems. A theoretical study. Brit. J. Anaesth 66:519-526, 1991.

39. Beneken J.E.W., Rideout V.C.: The use of multiple models in cardiovascular system studies: transport and perturbation methods. IEEE transaction in Bio-Med Engl. 15:281-289, 1968.

40. Achs M.J., Garfinkel D., Opie L.H.: Computer simulation of metabolism of glucose-perfused rat heart in a work jump. Am. J. Physiol. 243:R389-R399, 1982.

41. Cameron W.H.: A model framework for computer simulation of overall renal function. J. Theor. Biol. 66:551-572, 1977.

42. Fincham W.F., Tehrani F.T.: A mathematical model of the human respiratory system. J. Biomed Eng. 5:125-133, 1983.

43. Hancock P.A.: The simulation of human core temperature. Int J. Biomed Comp 12:59-66, 1981.

44. Carnevale N.T.: Numerical analysis of electronics in multicompartmental neuron models. J. Neuroscience Methods 19:69-87, 1987.

45. Granger D.N., Granger H.J.: Systems analysis of intestinal hemodynamics and oxygenation. Am. J. Physiol 245:786-796, 1983.

46. Cook R.I., Woods D.D., McDonald J.S.: Human performance in anesthesia: A corpus of cases. CSEL Report CSEL 91:003. Revision B 1991.

47. Mackenzie C.F.: Advances in trauma emergency care. In Anaesthesia Review 4 Ed L. Kaufman. Churchill Livingstone Edinburgh, pp 135-146, 1987.

Legends for Figures

Fig. 1 Deaths occurring in the operating room (OR) after admission to MIEMSS expressed as a percent of all early deaths (within first 24 hrs) over a 11 year interval.

Fig. 2 Survival rate for the first 24 hrs after admission to MIEMSS. A comparison of data over a 17 year interval.

Fig. 3 Deaths occurring in less than 24 hrs (early deaths) and more than 24 hrs after admission to MIEMSS 1980-87. The percent of patients (pts) with injury severity scores above and below 20 is shown for each year. In 1986 and 1987 compared to 1980 there were a greater number of more severely injured patients admitted yet the early deaths as a % of total admissions fell.

Fig. 4 Cervical spine injury admission to MIEMSS. Note highly seasonal changes. Six summer months (May - Oct) had 58 (73.4%) of total admissions. Letters at bottom of histogram represent months. From Mackenzie C.F. et al. J. Neurosurg. 62:843-849, 1985.

Fig. 5 Data on MIEMSS bed occupancy shows low patient days in January, February and April. Trauma anesthesia trainees will see less patients in these months. From Mackenzie C.F. (Ed). Chest Physiotherapy in the Intensive Care Unit. 2nd Edn. 1980. Williams and Wilkins, Baltimore. p 349.

Fig. 6 Some of the tasks, cognitive processes and interactions that an anesthesiologist employs to give an anesthetic, and to identify and treat problems that are outlined in this schematic. Reproduced with permission from GABA D.M.: Anesthesia Crisis Resource Management Course, Palo Alto, 1991.

Fig. 7 Factors potentially involved in human error. Dynamic decision making may correct the problem or a critical incident may occur and the outcome maybe adverse. Reproduced with permission from Gaba D.M. Human Error in Anesthesia Conference 1991.

Fig. 8 A.S.A. decision tree for management of the difficult airway showing 5 possible paths (see text). Decisions are diamond shaped, tasks are rectangular. Time is handwritten in mins (eg. 10') or seconds (eg. 30") for completion of decision or tasks. Y = yes, N = no, END = tracheal intubation achieved.

Fig. 9 After iteration of MicroSAINT 1000 times, the distribution of times for intubation of the difficult airway is shown on this histogram. Time in seconds is on the X axis, the number of occasions the trachea was intubated in a given time (counts) is on the Y axis.

Fig. 10 The number of occasions each of five paths shown in Fig 8 were chosen in 1000 microSAINT iterations is shown in this histogram.

Fig. 11 Time for intubation of the trachea is shown for 1000 iterations of microSAINT employing the times handwritten in Fig. 8. Time in seconds is on the Y axis.

Fig. 12 A microphone suspended from the roof of the resuscitation area and operating room (O.R.) and a fixed miniature video camera are interfaced with physiological monitors and the data is overlayed together with a time code signal on the video. PC-CPU = personal computer central processing unit. VCR = video recorder.

Fig. 13 Video analysis configuration employs a PC 386 20 Mhz with 80 MB HD. The VCR and color monitor are frame accurate and are driven by OCS video analysis software. At a minimum one anesthesiologist and one experimental psychologist views the video and analyses it.

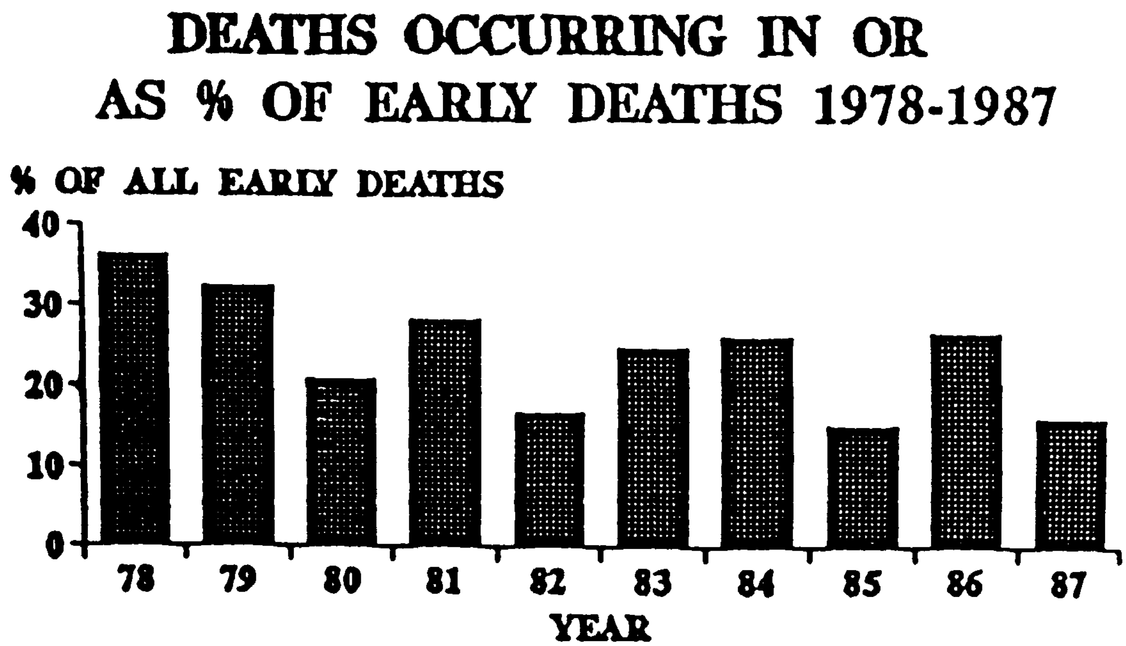


Fig. 1 Deaths occurring in the operating room (OR) after admission to MIEMSS expressed as a percent of all early deaths (within first 24 hrs) over a 11 year interval.

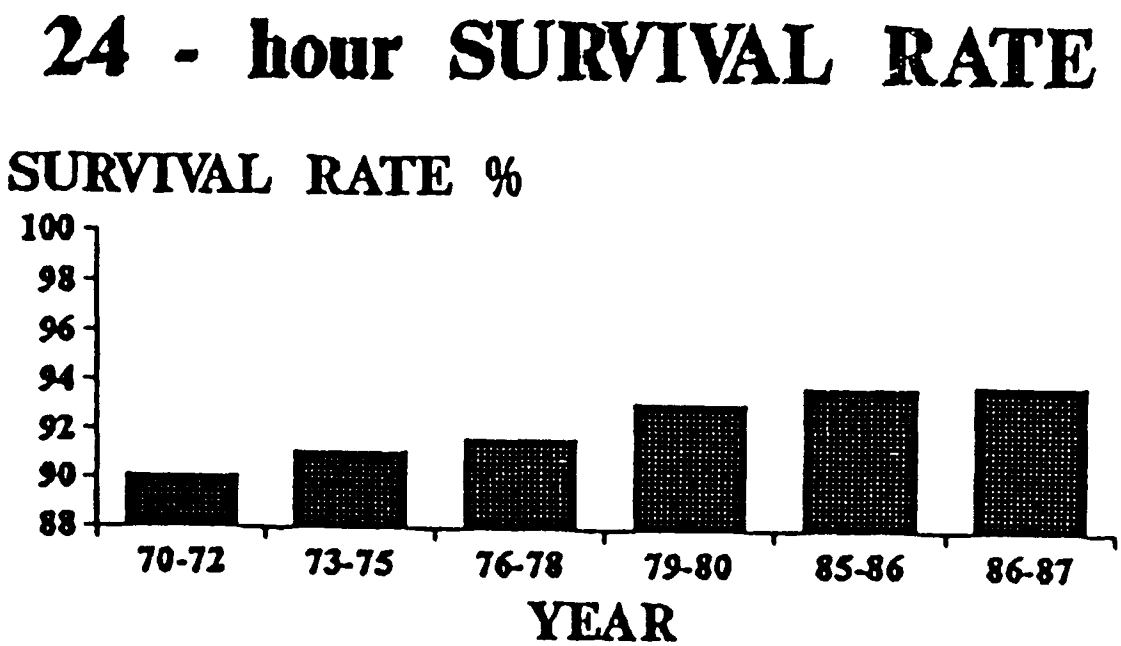


Fig. 2 Survival rate for the first 24 hrs after admission to MIEMSS. A comparison of data over a 17 year interval.

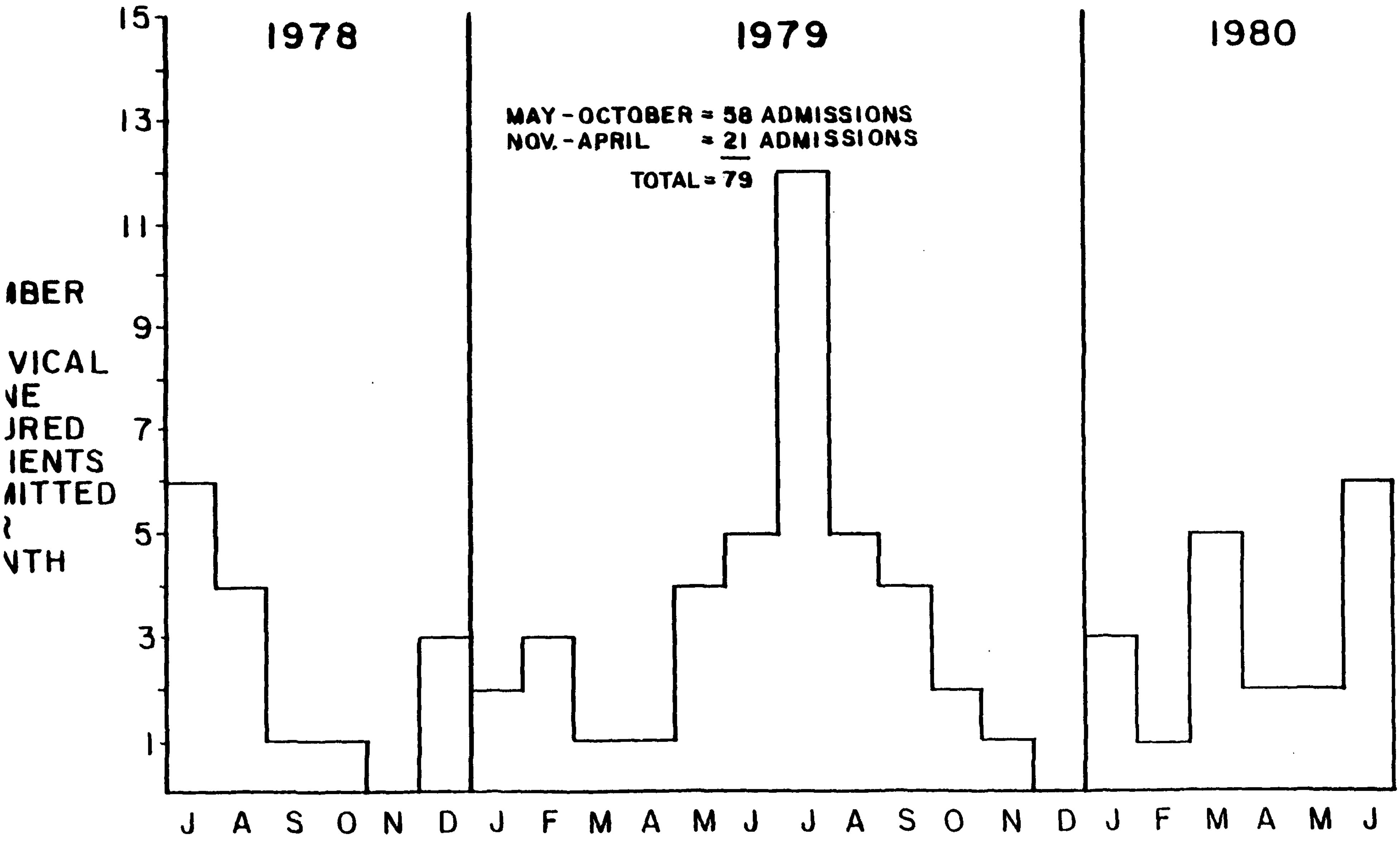
	1980	1986	1987
Early deaths Less than 24 hours	6.8% (96 pts)	4.8% (100 pts)	4.7% (99 pts)
Deaths after 24 hours	5.7% (108 pts)	5.2% (108 pts)	5.3% (113 pts)
ISS 20+	11.8% (119)	17.9% (322)*	15.7% (308)*
ISS 12-19	11.8% (119)	22.6% (420)	24.2% (476)°
ISS less than 11	50.7% (512)+	36.6% (679)	39.8% (782)

* $p<0.01$ 1987 and 1986 v 1980
o $p<0.01$ 1987 v 1980
\+ $p<0.01$ 1980 v 1986 and 1987

Fig. 3: **Deaths occurring in less than 24 hrs (Early deaths) and more than 24 hrs after admission to MIEMSS , 1980-87. The % of patients (pts) with Injury Severity Scores above and below 20 is shown for each year. In 1986 and 1987 compared to 1980 there were a greater number of more severely injures patients admitted yet the early deaths as a % of the total admission fell.**

Fig. 4 (ORIGINALS BEING PHOTOGRAPHED Figs. 4-13

INCIDENCE OF CERVICAL SPINE INJURIES ADMITTED TO
THE MARYLAND INSTITUTE FOR EMERGENCY MEDICINE, UNIV. OF MARYLAND
JULY 1978 — JUNE 1980



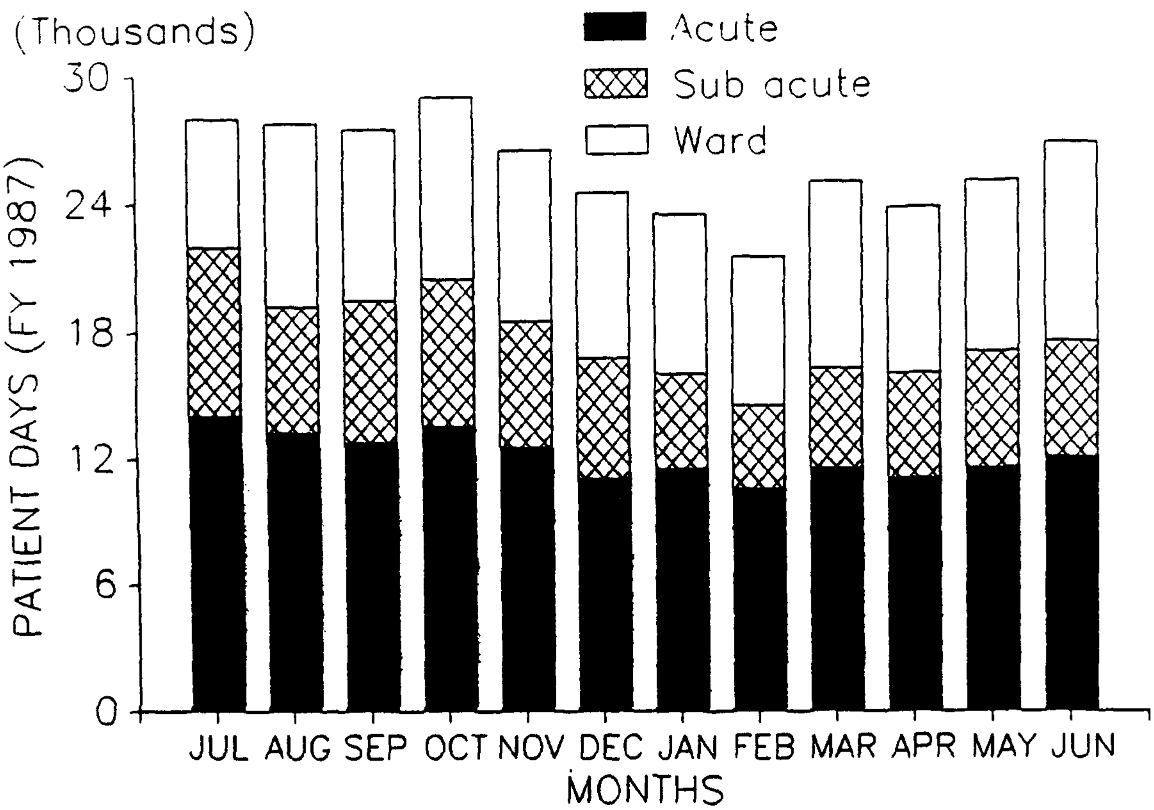
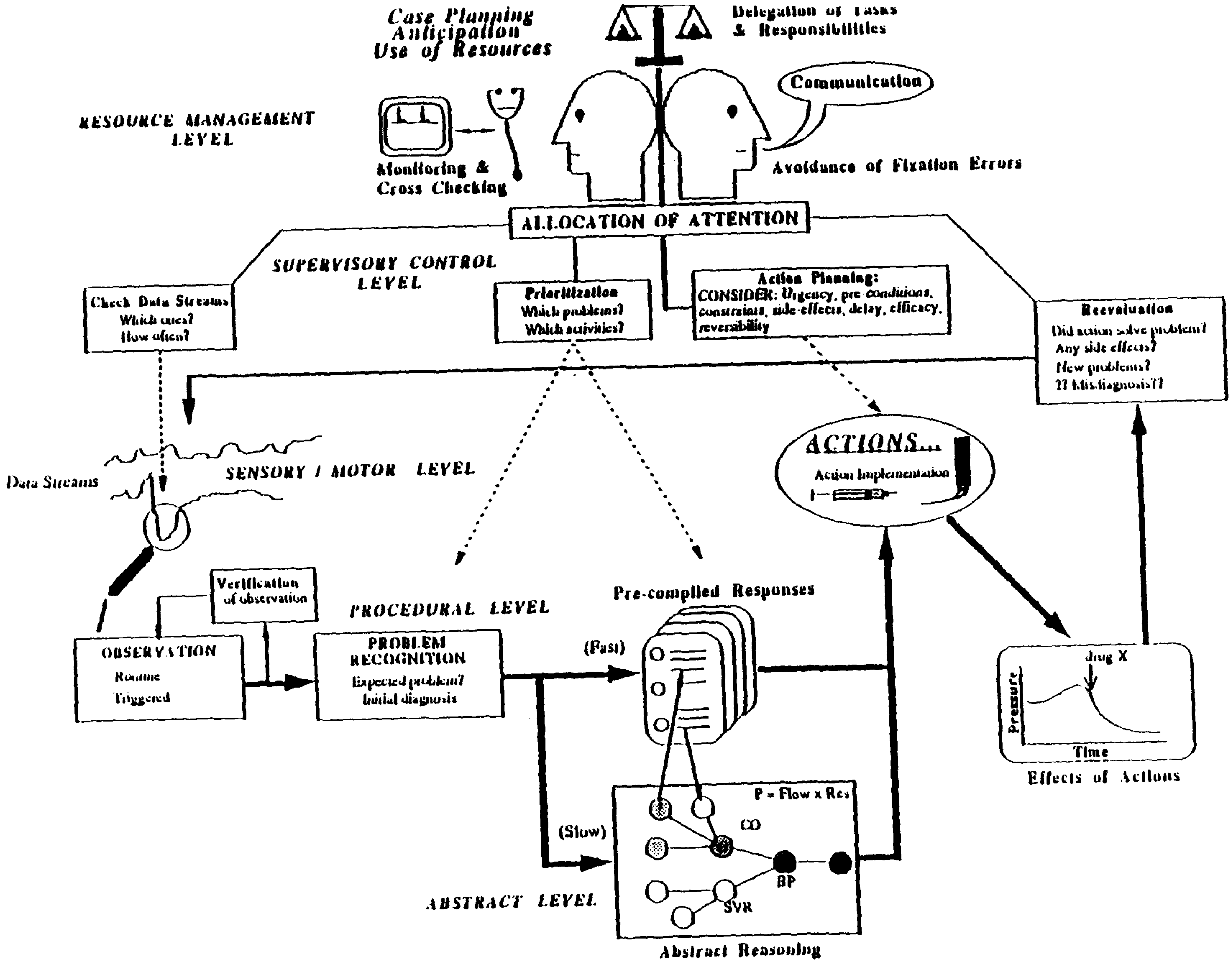
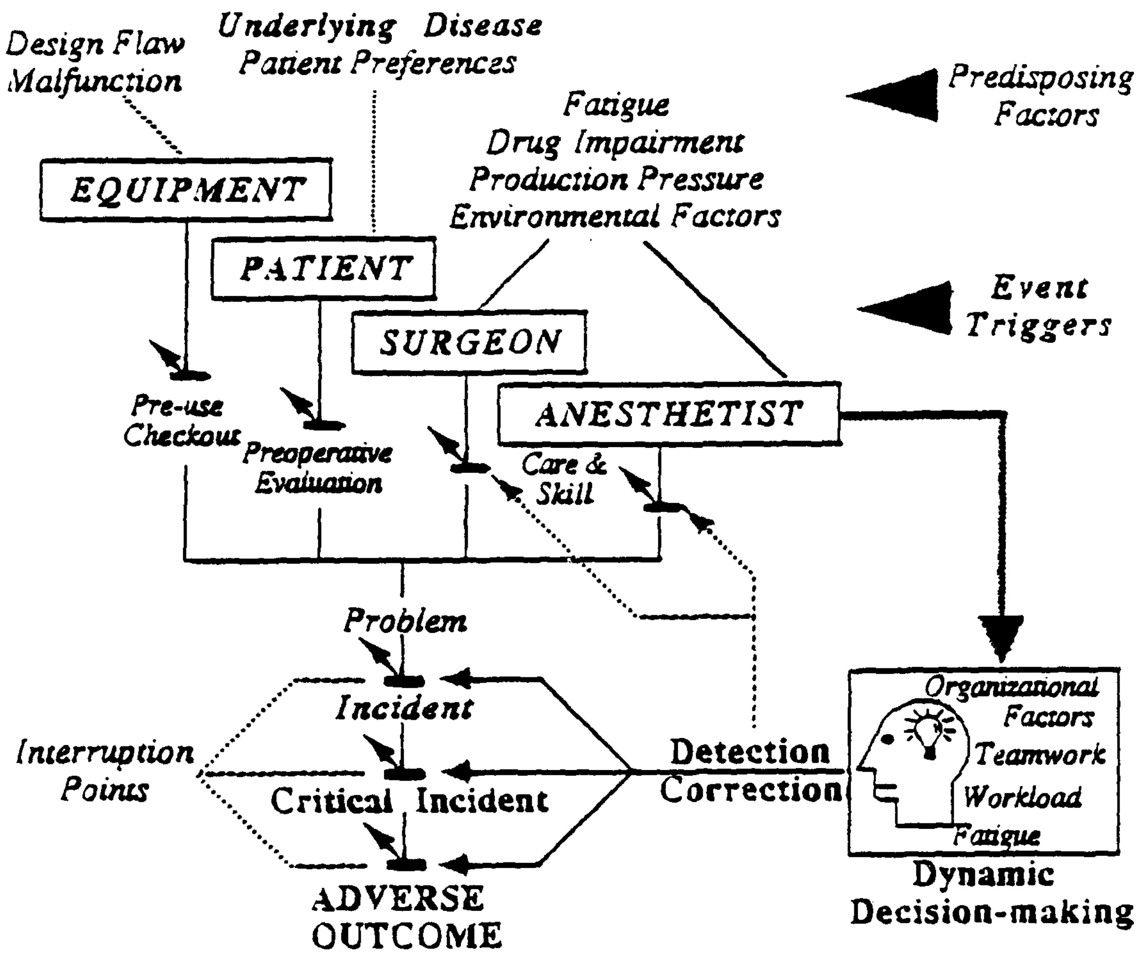

(Thousands)
Acute
Sub acute
Ward
PATIENT DAYS (FY 1987)
30
24
18
12
6
0
JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY JUN
MONTHS

Fig. 5



Case Planning
Anticipation
Use of Resources
Delegation of Tasks
& Responsibilities
RESOURCE MANAGEMENT
LEVEL
Communication
Monitoring &
Cross Checking
Avoidance of Fixation Errors
ALLOCATION OF ATTENTION
SUPERVISORY CONTROL
LEVEL
Check Data Streams
Which ones?
How often?
Prioritization
Which problems?
Which activities?
Action Planning:
CONSIDER: Urgency, pre-conditions, constraints, side-effects, delay, efficacy, reversibility
Reevaluation
Did action solve problem?
Any side effects?
New problems?
?? Misdiagnosis??
Data Streams
SENSORY / MOTOR LEVEL
ACTIONS...
Action Implementation
Verification
of observation
PROCEDURAL LEVEL
Pre-compiled Responses
OBSERVATION
Routine
Triggered
PROBLEM
RECOGNITION
Expected problem?
Initial diagnosis
(Fast)
(Slow)
Drug X
Pressure
Time
Effects of Actions
P = Flow x Res
CO
BP
SVR
ABSTRACT LEVEL
Abstract Reasoning

Fig. 6

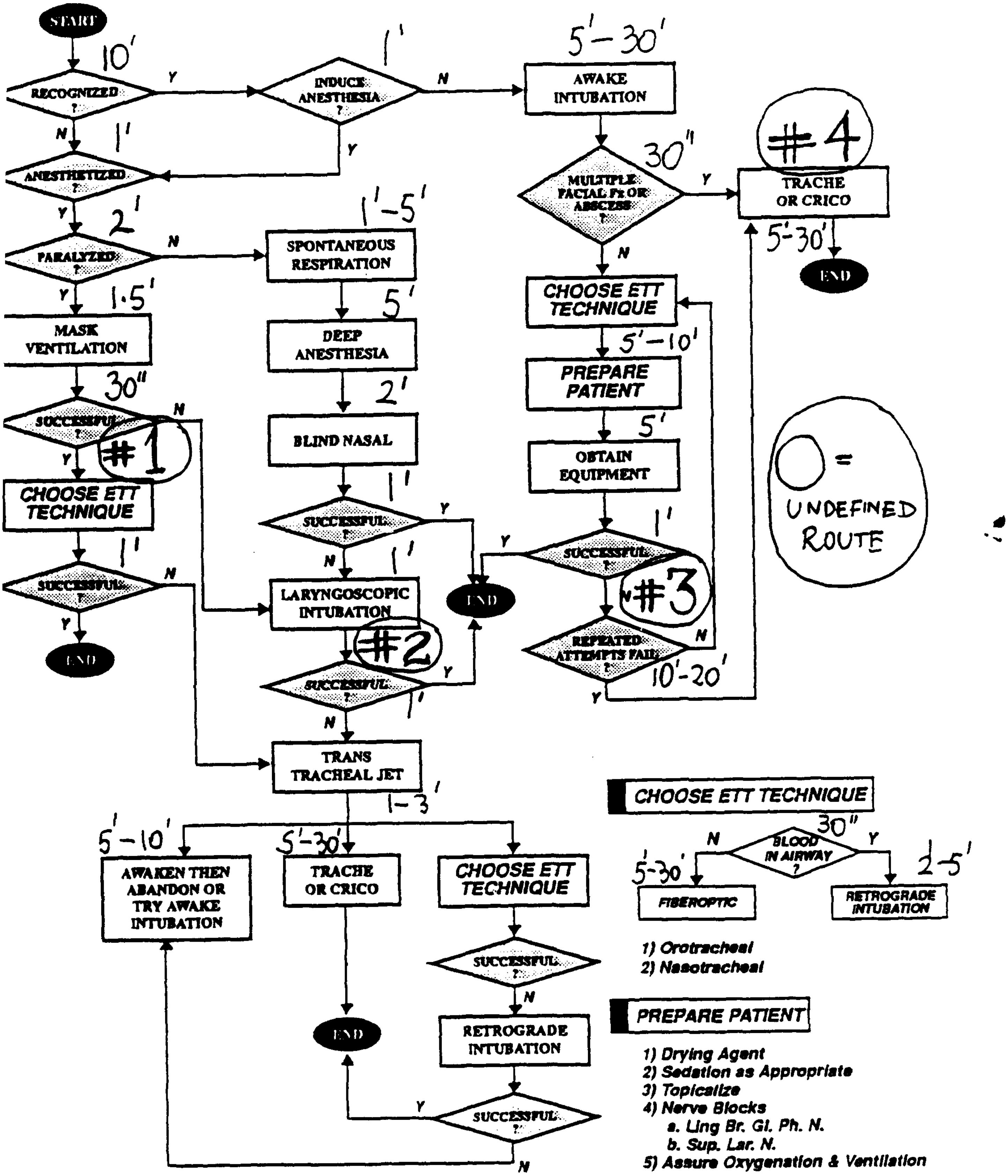


Figs. 6 and 7
Reproduced with permission from Gaba D.M., Crisis Resource Management: revised from Gaba D.M. Human Performance Issues in Anesthesia Patient Safety. In Problems in Anesthesia. Vol. 5 #2 June 1991 Lippincott Philadelphia.

Fig. 7

Fig. 8

MANAGEMENT OF THE DIFFICULT AIRWAY



CHOOSE ETT TECHNIQUE

1) Orotracheal
2) Nasotracheal

PREPARE PATIENT

1) Drying Agent
2) Sedation as Appropriate
3) Topicalize
4) Nerve Blocks
   a. Ling Br. Gl. Ph. N.
   b. Sup. Lar. N.
5) Assure Oxygenation & Ventilation

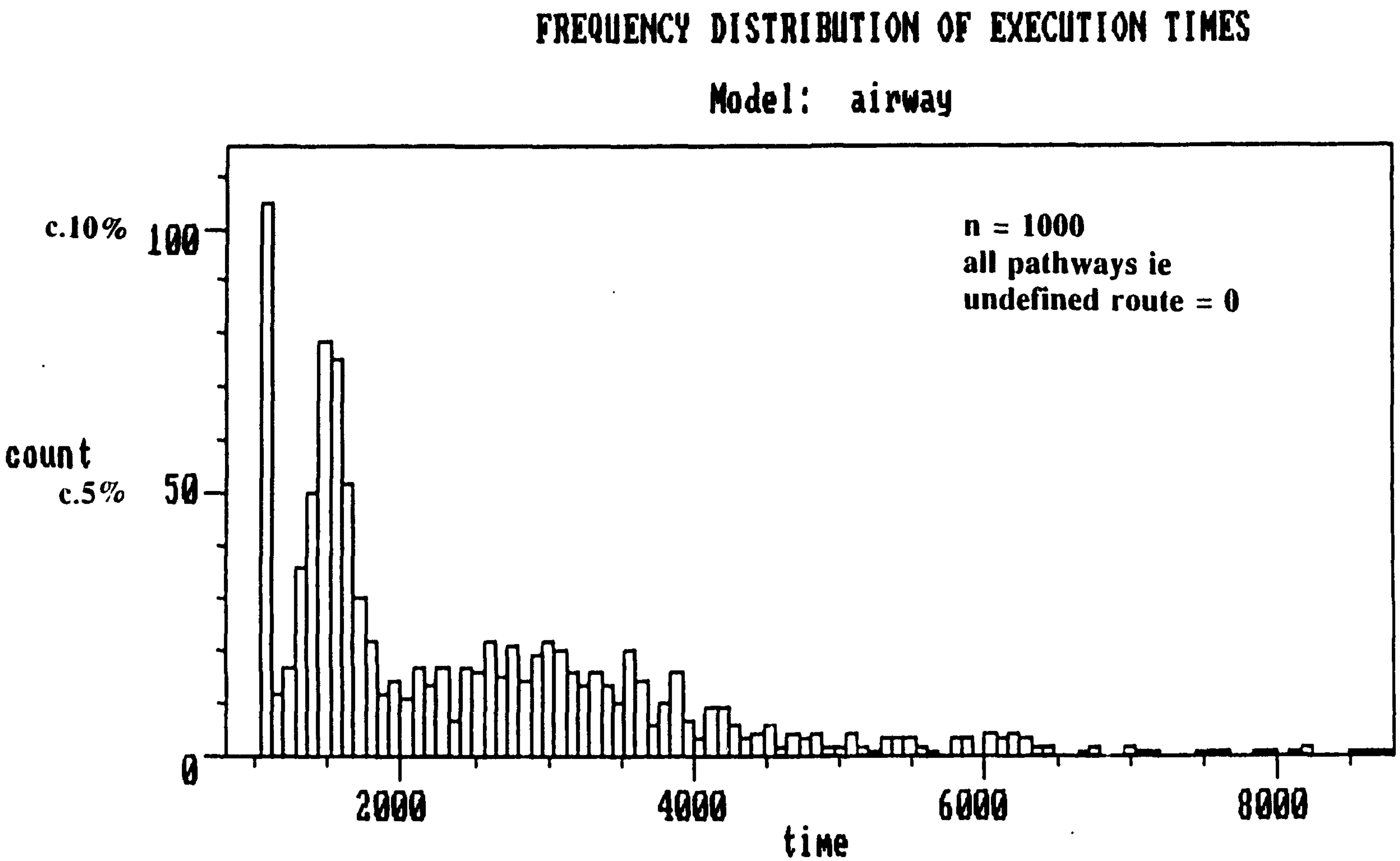

FREQUENCY DISTRIBUTION OF EXECUTION TIMES
Model: airway
n = 1000
all pathways ie
undefined route = 0
c.10%
100
count
c.5%
50
0
2000
4000
6000
8000
time

Fig. 9

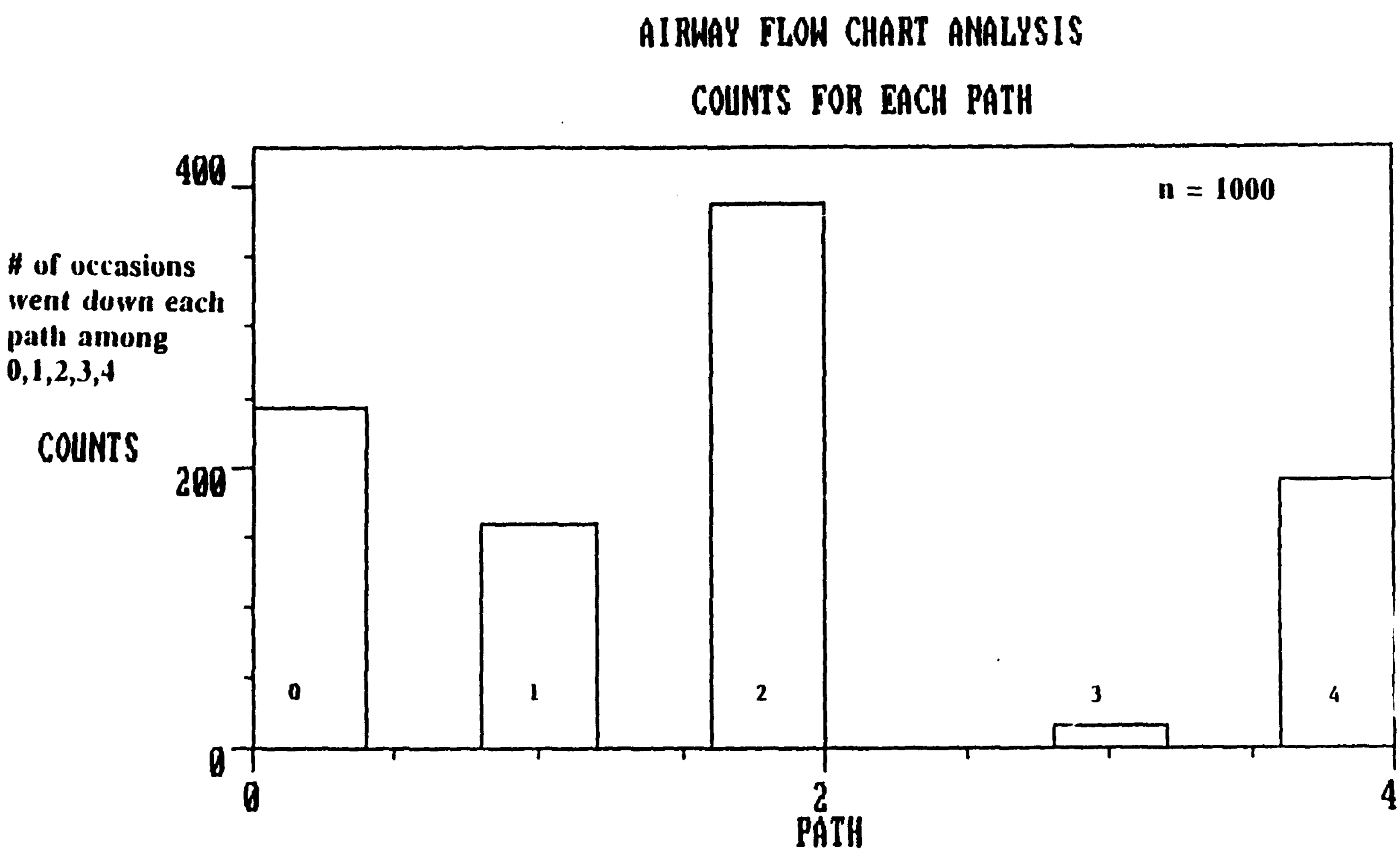

AIRWAY FLOW CHART ANALYSIS
COUNTS FOR EACH PATH
n = 1000
# of occasions went down each path among 0,1,2,3,4
COUNTS
400
200
0
0
1
2
3
4
0
2
4
PATH

Fig. 10

MANAGEMENT OF THE DIFFICULT AIRWAY
Complete Time Through Different Paths

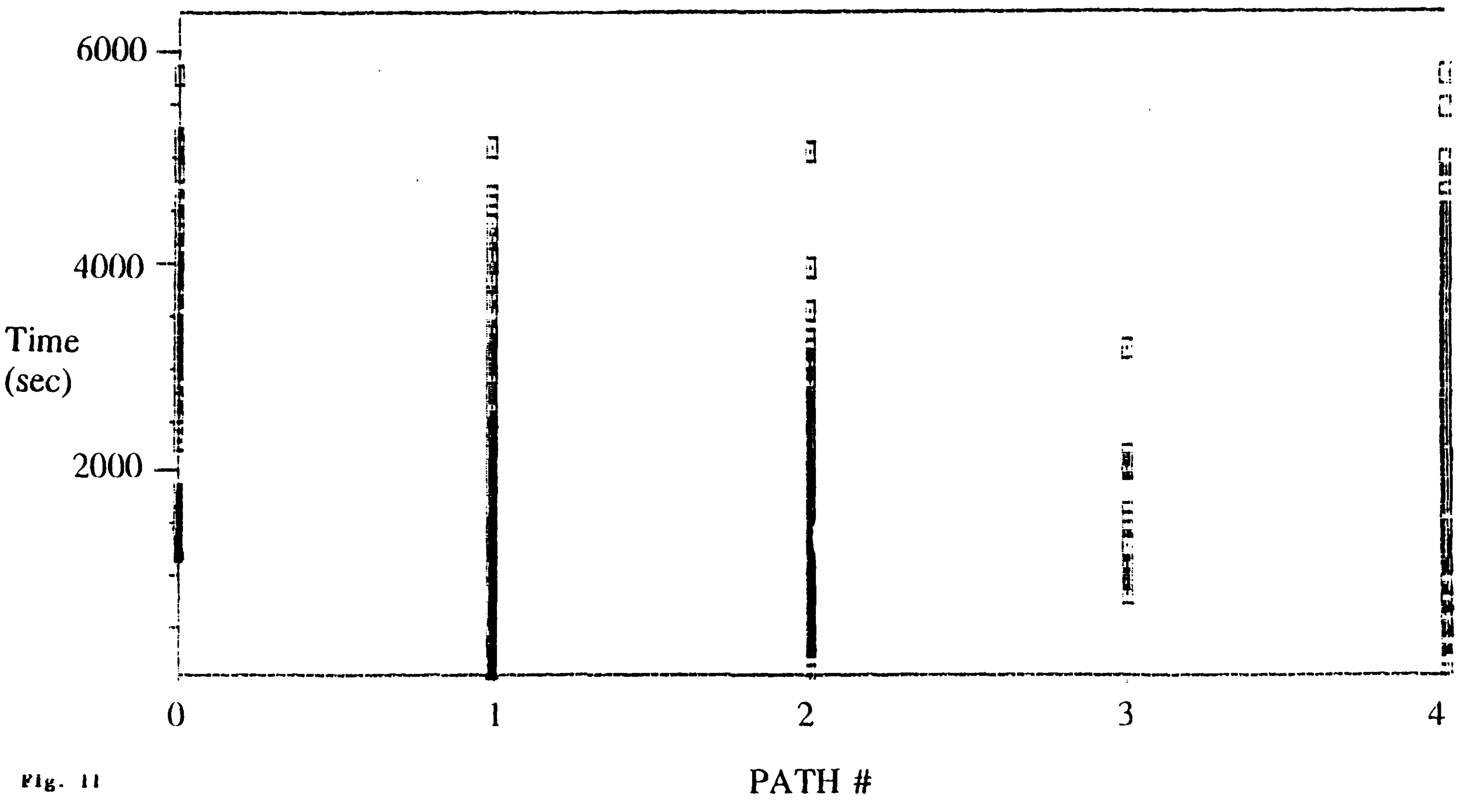


Fig. 11

VIDEO and DATA ACQUISITION EQUIPMENT CONFIGURATION

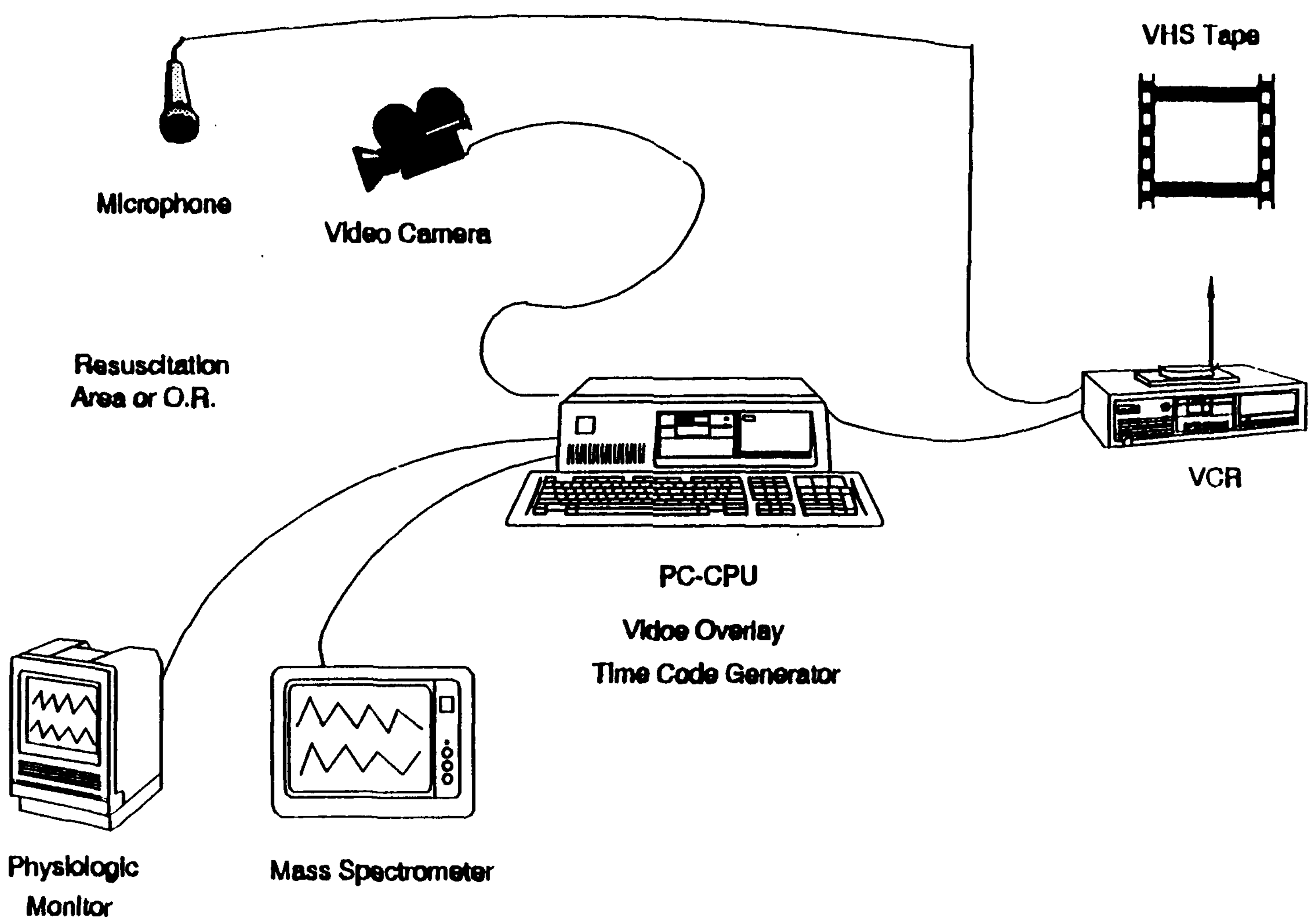


Fig. 12

Video Analysis Configuration

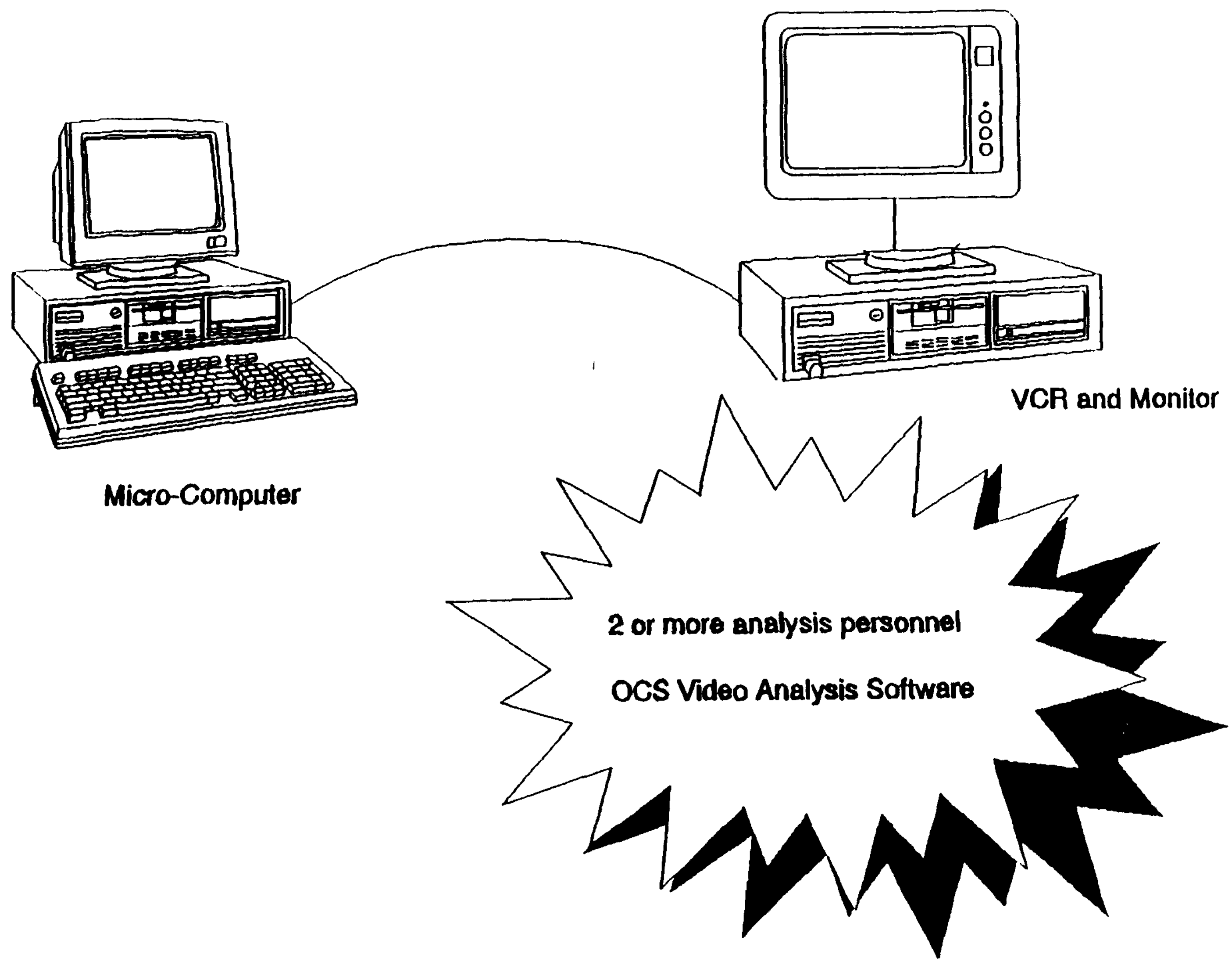


Fig. 13